STUDIES OF RESISTANCE OF 92 SORGHUM AND 38 MAIZE CULTIVARS TO 4 SPECIES OF STORED-PRODUCT INSECTS

by

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INTRODUCTION

Sorghum and maize are grown extensively in many countries of the world. They are used as food by man, and as in the United States, as feed for livestock.

Both sorghum and maize are attacked by stored-grain insects in farm and commercial granaries. Total losses of the world production of cereals due to storage insects have been estimated at about 10% (Munro, 1966).

The rapid human population increase as well as the current emphasis on production, storage, and marketing of grain free from insect damage and contamination make it more important that insect infestations in grain be prevented and controlled. Control is often accomplished by chemical treatment which is costly and may result in undesirable residues.

Stored-product insect control by using resistant crop varieties is being explored to reduce the possible undesirable effects of insecticides. If crop varieties resistant to stored-product insects were available to growers, control could be greatly enhanced with reduced cost and reduced usage of chemicals.

Painter (1951) stated that the first potential sources of resistance should be the common varieties grown and adapted in the area where the experiments are being conducted. If resistance can be found among such varieties, breeding for a satisfactory variety is simplified.

The primary purpose of this research was to evaluate resistance to 4 important stored-product insects of cultivars of sorghum and maize, most harvested from field trials in Kansas, and to study factors which may cause the resistance. The insect species used were the rice weevil, *Sitophilus oryzae* (L.), maize weevil, *Sitophilus zeamaize* (Motsch.), lesser grain borer, *Rhyzopertha dominica* (F.), and the red flour beetle, *Tribolium castaneum* (Hbst.)

The female weevil eats a hole in the kernel, lays an egg in it, then plugs the hole with a gelatinous material. The larva remains inside the kernel where it develops through 4 larval instars and the pupal stage before emerging as an adult.

The female lesser grain borer lays eggs outside the kernels. After hatching, the small larva chews its way into the kernel where it develops through 4 larval stages and the pupal stage before emerging as an adult.

Red flour beetles, unlike weevils and lesser grain borers, are external feeders in the larval and adult stages, and usually start feeding on the germ, then attack the endosperm. The larva commonly develops through 7-8 instars.

REVIEW OF LITERATURE

Host Resistance in Sorghum Grain

Ali (1950) studied 15 varieties of sorghum and found that only Martin and Cody were suitable for reproduction of the rice weevil. However, a low moisture content (9.6%) in each of the sorghums may explain the high level of resistance he obtained.

In India, Samuel and Chatterji (1953) studied the resistance of varieties of jowar (sorghum) to 6 species of stored grain insects, including the rice weevil, lesser grain borer, and red flour beetle.

By using weight loss and percentage of damaged grain, they found Js 20, a non-huskable variety, almost fully resistant to all of the insect species except the lesser grain borer. No variety was immune and the degree of resistance or susceptibility of the different varieties seemed to depend upon a number of factors such as hardness, texture, husk cover, and moisture content of the grain.

Victoria Lieu, in unpublished work done at Kansas State University in the 1950's, noted that the rice weevil, granary weevil, and lesser grain borer did not reproduce or survive in two non-waxy sorghum varieties, Double Dwarf Yellow Sooner and Double Dwarf White Sooner, of 12 per cent moisture content.

Doggett (1957) described a no-choice test method of estimating weevil damage to 17 different sorghum varieties. He found a positive relationship between the low level of damage to sorghum grains by weevils and thickness of the corneous endosperm shell. He also observed that small grains appeared less damaged than larger ones. Doggett (1958) stated that a thick corneous endosperm shell in grain had been successfully incorporated in a breeding program in Tanganyika for weevil resistance.

Morrison (1964) found that whole kernels of Atlas sorghum yielded more maize weevil adult progeny than halved or coarsely ground kernels. This tends to support Doggett's finding regarding kernel size.

Davey (1965) studied the factors such as moisture content and hardness of the endosperm, that affected the susceptibility of sorghum kernels to the attack of rice weevils. She devised a method to measure the relative amounts of vitreous corneous and mealy endosperm in a seed and found that the greater the percentage of vitreous endosperm, the higher the degree of resistance to the rice weevil.

Davey (1964) stated that eggplug counts and X-rays were unreliable methods for counting eggs and young larvae of the rice weevil because they are small and difficult to see. She concluded that counts of emerging adults were adequate for comparing damage by weevils to different varieties of sorghum.

Russell (1962) found that harder-grained varieties, with the exception of Texioca-54, were least attractive to the maize weevil for oviposition. Hardness was measured by average per cent weight lost by pearling for a given period. Per cent mortality of immatures was not significantly different among the varieties, thus, first generation emergence paralleled the oviposition findings. Oviposition preference was greatest for the larger seeds.

Russell and Rink (1965) studied the effects of sorghum varieties on the development of maize weevils and concluded that their reactions were similar to those of rice weevils. They tested 4 varieties using length of developmental period and number of first generation progeny as indicators of resistance. Resistance was correlated to hardness, i.e., the softer the variety the shorter was the developmental period.

Russell (1966) found that harder varieties of sorghum reduced rice weevil adult longevity and oviposition rate, which results in reduced grain damage.

By using flour of several varieties of sorghum, Dang and Pant (1965) observed a difference in larval survival of red flour beetle and stated that chemical factors in the sorghum may have been responsible for the differences.

Rogers (1970) screened 1511 cultivars of sorghum received from the International Germ Plasm Seed Bank, Chapingo, Mexico, for resistance to the maize weevil. He found that 161 cultivars produced as few as or fewer progeny than his resistant check (Double Dwarf Early Shallu). He also found that an increase in relative humidity gave an increase in the number of progeny produced by 1 resistant and 2 susceptible varieties but the increase was much smaller for the resistant variety than for the 2 susceptible varieties.

Hunkapiller (1970) screened 269 cultivars of sorghum to determine resistance to the maize weevil and lesser grain borer. Only 13 of the cultivars exhibited some degree of resistance to maize weevil when compared to the susceptible check. Double Dwarf Early Shallu was the most resistant and Shambul from Nigeria the most susceptible cultivar tested. Only 49 of the cultivars exhibited some degree of resistance to lesser grain borer. Martin X Norg-mid 7319-1 was the most resistant and 60M 1459 the most susceptible cultivar tested. Size of kernels did not appear to affect resistance or susceptibility. The yellow cultivars tested were the most susceptible to both insects.

Rout (1973) compared red flour beetle resistance of 21 sorghum cultivars of world-wide origin, which Rogers (1970) found to be most resistant or most susceptible to maize weevils. Rout compared samples of these, grown in Kansas in 1970, to red flour beetles using sound kernels, 90% sound: 10% broken kernels, and flour, infested with 25 0-24-hr-old larvae. Some degree of resistance in the sorghum cultivars was observed. No progeny emerged in the sound kernels of cultivar 173 while the percentage of larvae which developed to adults in sound kernels of other cultivars ranged from 21.33 to 89.33. Percentage survival to adult was highest to lowest in flour, sound:broken kernels, and sound kernels, respectively. The larval-pupal periods were shorter in flour than in sound:broken or sound kernels.

Using 26 sorghum cultivars, which Rogers (1970) found to be most resistant to the maize weevils and grown in Kansas in 1970, Lange (1973) found that maize weevil oviposition and kernel hardness were negatively correlated and that there was less weevil emergence from the resistant cultivars. Soil nitrogen fertilization had little effect on resistance to maize weevils but grain maturity at harvest did; mature grain was more resistant to insect attack.

Stevens and Mills (1973) compared the suitability of 2 free-choice tests (random-distribution and uniform-distribution) with a no-choice technique to determine relative resistance of 36 varieties of sorghum to rice weevils and found that the 3 types of tests were nearly equal for ranking varieties of sorghum as to rice weevil resistance; however, more progeny were produced in the no-choice tests.

Host Resistance in Maize Grain

The value of husk cover in preventing rice weevil injury to ear corn has been discussed by Smith (1909), Wilson (1912), Hinds (1914), Kyle (1918), Back (1919), Cartwright (1930), Eden (1952), Floyd and Powell (1958), and Floyd, Oliver, and Powell (1959).

Warren (1954) reported that the rice weevil was capable of surviving in hulled teosinte, a primitive type of corn.

Singh and McCain (1963) reported a highly significant positive correlation between sugar content of corn kernels and extent of field infestation by rice weevils, and a negative correlation between kernel hardness and rice weevil infestation.

Pant, Kapoor, and Pant (1964) studied the relative resistance of 11 varieties of maize to the rice weevil and noted that the flint type of maize varieties tended to fall in the resistant groups and the dent type in the susceptible groups.

Schoonhoven (1972) stated that selection for maize weevil resistance in corn kernels was successful in dent lines, mainly derived from an open-pollinate variety, but was not successful in flint lines. He measured hardness of kernels with opaque (high lyzine) and normal endosperm by applying 4 kg pressure on a diamond crystal placed against the back of kernel and found no correlation between resistance and hardness. He also stated that damage to the pericarp such as hot water treatment, scratching or rubbing between sandpaper made the kernel susceptible. Kernel size, moisture equilibration of the sample in screen-lidded cages prior to testing, or extended storage periods did not influence progeny number but temperature did.

McCain, Eden, and Singh (1964) described a laboratory technique for selecting rice weevil resistance in corn varieties. A promising test was designed that offered weevils free-choice of several varieties. Weevils readily selected the most susceptible hybrids.

Diaz (1967) suggested that, in 139 Mexican maize collections he screened, the resistance to the maize weevil came from lowlands in Tepalcingo, Morelos, Mexico, or primitive corn from other areas. He also stated that the best measure of resistance in free-choice and no-choice tests was in the number of emerged weevils.

VanDerSchaaf, Wilbur, and Painter (1969) screened 337 corn strains using the maize weevil in a no-choice and free-choice test. They found 20 strains, which had their origin in lowland tropical regions, with some degree of resistance. This agrees with Diaz (1967).

Kirk and Manwiller (1964) developed a method of supplementing low field populations of weevils for resistance ratings of breeding material and new hybrids. They broadcast collected weevils (30,000-70,000 insects/acre) through yield test fields. Resistance or susceptibility of the corn to the weevils was evaluated by using per cent ears infested.

Rhine and Staples (1968) found that high amylose content in maize varieties adversely affected larval nutrition of rice weevils and granary weevils, but did not affect either nutrition or larval survival of lesser grain borer or red flour beetle. It was suggested that larval survival of some stored-product insects may have been influenced by other resistant factors since the high amylose and normal amylose maize were grown under different breeding programs.

Hopkins (1970) screened 314 genetic sources of corn from the International Germ Plasm Seed Bank, Chapingo, Mexico for resistance to the lesser grain borer. He stated that corn sources which had large amounts of hard endosperm and small amounts of soft endosperm were more resistant to the lesser grain borer.

Host Resistance in Wheat, Rice, and Other Stored Grain

Ewer (1945) noted that larger grains of wheat were preferred for oviposition by granary weevils.

Singh, Kundu, and Gupta (1968) tested 29 varieties of wheat and suggested that hardness could be a component of resistance to the rice weevil.

Breese (1960) reported that sound, mature rough rice with intact husks appeared to be almost immune to infestation by rice weevils. Infestation developed in grains with lemma and palea separated, but the developing adults were often unable to emerge. Rossetto (1966) screened 1700 varieties of rough rice for resistance to maize weevils and reported the same relationship.

Russell (1968) tested 6 American varieties of rice for resistance to rice and maize weevils. He found that grains with gaps between the palea and lemma were more susceptible to weevil oviposition.

Sinha (1969) determined the reproduction of 5 cosmopolitan stored-grain insects on 39 varieties of cereals grown in Canada and reported the low resistance of the commonly-grown barley varieties to red flour beetles. Hulls of oats prohibited reproduction of the granary weevil and lesser grain borer but none of the oat varieties were particularly resistant to red flour beetle.

GENERAL MATERIALS AND METHODS

Sorghum Samples

All sorghums used in the studies were grown in the field in 1972. Eighty-two cultivars were from field trials grown in Brown County, Kansas, by the Kansas Agricultural Experiment Station, 8 cultivars (C42Y, C42Y-1, F65A-1, F65a, BR54, BR54-1, E57-1, and C42C-1) were obtained from Sorghum Research, DeKalb AgResearch, Inc., Lubbock, Texas, and 2 cultivars (MP10 Sh and DDES) were obtained from Fort Hays Kansas Agricultural Experiment Station, Hays, Kansas.

Maize Samples

All 38 maize cultivars used were from field trials grown in Republic County, Kansas, by the Kansas Agricultural Experiment Station in 1972.

Storing Grain Samples

Upon receipt, the grain samples were placed in a freezer for at least 2 weeks at approximately $-16^{o}C$ to destroy any possible insect infestations and then stored in a cold room at $4^{o}C$.

Rearing Room

All insect cultures and tests were kept in a rearing room with constant $67 \pm 3\%$ relative humidity (RH) and a temperature of $27 \pm 1^{o}C$. An automatic mist-type humidifier was used to maintain the relative humidity and thermostatically controlled electric heating and cooling units maintained the temperature. The culture room was maintained in a 12:12 light, dark photoperiod.

Sources of Insects

Insects used in the studies were obtained from stock cultures maintained in the Department of Entomology Stored-Product Insects

Laboratory. The rice weevils, lesser grain borers, and red flour beetles originated from field collections in Kansas and have been maintained in the laboratory for several years. The maize weevil culture was obtained from Stuttgart, Arkansas in 1955 and since maintained in the laboratory.

Maintenance of the Stock Insect Cultures

Insect cultures were kept in wide-mouth quart jars having caps fitted with both 60-mesh brass screens and 9 cm kelthane-treated filter papers for mite control. About 25 g of hard red winter wheat at 12.5 to 13.5% moisture content were placed in each jar for weevils and lesser grain borers, and about 200 g of a mixture of 60 parts of whole wheat flour, 40 parts of cornmeal, and 5 parts of dry yeast was used as a rearing medium for red flour beetles. About 200-300 unsexed adult weevils, 300-400 unsexed adult lesser grain borers, and 300-400 unsexed adult red flour beetles were allowed to oviposit in each appropriate medium for 7 days and then removed so that the age of the progeny insects was fairly uniform.

Testing Chambers

Five circular, wooden chambers were used in a preference test to determine the relative resistance of the samples (Plate I). Each chamber had a diameter of 42 cm and a depth of 8.5 cm. Twenty 48 x 48 x 6 mm plastic box lids which held grain samples during oviposition could be arranged in a circle near the chamber wall. The chamber was closed with a circular piece of 3/16" masonite and sealed with masking tape to

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EXPLANATION OF PLATE I

Fig. 1. Test chamber and lid in which 19 plastic box lids of maize samples were arranged.

Fig. 2. Twenty box lids containing sorghum samples arranged in the test chamber, and pieces of paper leaned against the lids to serve as bridges for testing with red flour beetles.

PLATE I

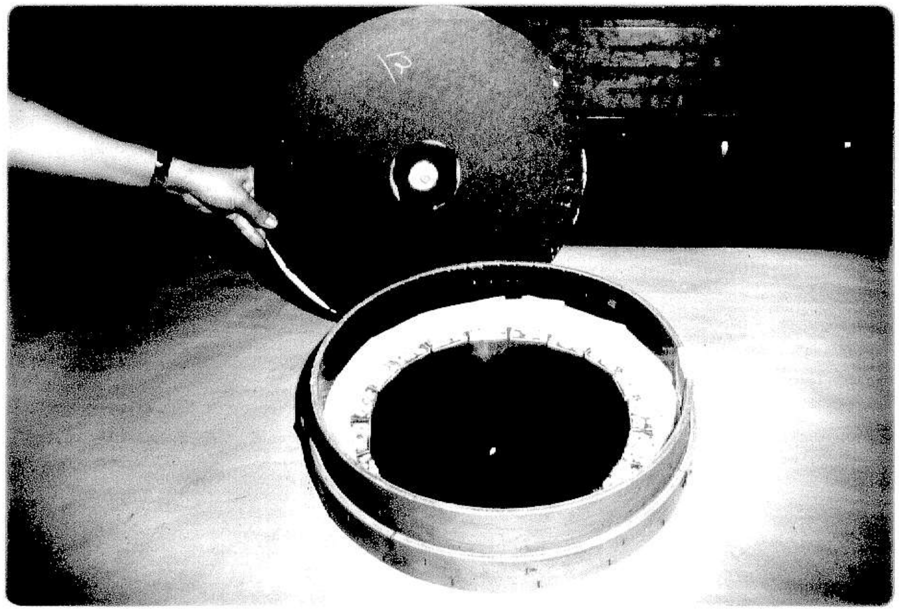

Fig. 1

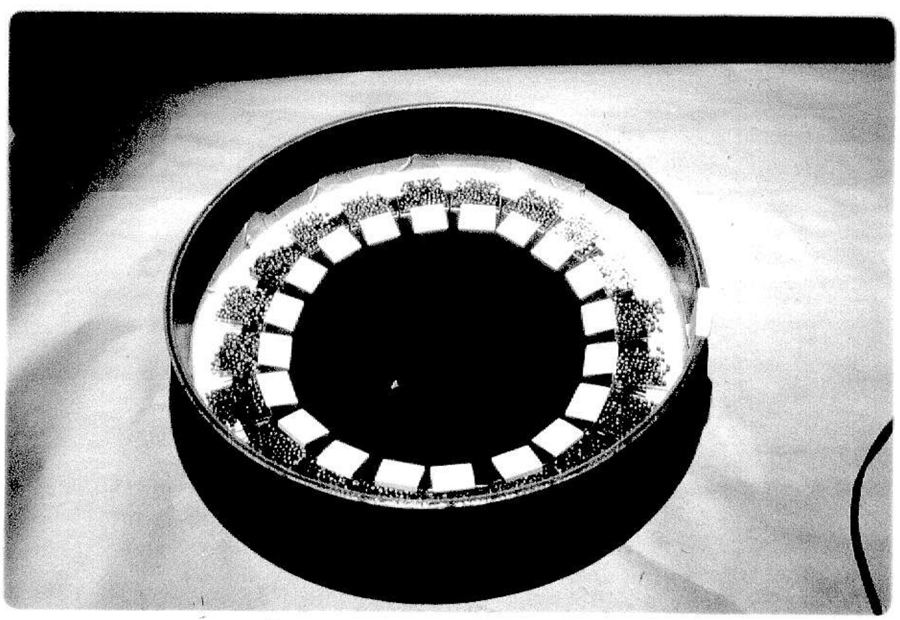

Fig. 2

prevent escape of insects. In the center of the lid was a circular opening (9 cm diam) closed with 60-mesh brass screen. A small hole in the center of the screen through which insects could be introduced was closed with a rubber stopper.

Grain Equilibration

Measurement of the moisture content of each sample was impractical because of the small amount of grain, but all samples (100 kernels of each sorghum and 20 maize kernels) were placed in 48 x 48 x 18 mm plastic boxes with lids having 60-mesh screen in the rearing room (15 days for sorghum and 21 days for maize) so moisture content could equilibrate with the 67% relative humidity.

RESISTANCE OF SORGHUM CULTIVARS TO RICE WEEVILS

Materials and Methods

Three replicates of 100 kernels each for each cultivar, which had been equilibrated in the rearing room, were selected randomly and placed in 48 x 48 x 6 mm plastic box lids. Twenty lids were arranged in each testing chamber (Plate I, Fig. 2). The chamber was covered with a lid and sealed with masking tape before dropping 200 7 to 14-day-old adult rice weevils through a central hole. The chamber was then placed in the rearing room. The rice weevils were allowed free-choice for ovi-posting among all the cultivars in the chamber for 5 days and then removed. The sorghum samples were transferred to 48 x 48 x 18 mm plastic boxes and covered with screened lids, put in cardboard trays and returned to the rearing room. Beginning 25 days after the parent weevils were removed the numbers of emerged adult progeny were counted and recorded daily until no progeny emerged from the cultivar for 7 days.

Results and Discussion

The smallest average number of rice weevil progeny emerged from cultivar MP10 Sh (8/replicate) and the largest average number (71.7/replicate) from cultivar X101 (Table 1). The average number that emerged from the remaining 90 cultivars ranged from 26.0 to 69.3/replicate. Statistical analysis (Table 2) revealed significant differences in the numbers that emerged from different cultivars. Based on a least significant difference (5% level) of 11.53, the sorghum cultivars could be placed in 4 groups according to the degree of resistance: (1) the most resistant cultivar, MP10 Sh, (2) the 11 resistant cultivars from which the average numbers of emerged insects ranged from 26.0 to 36.3/replicate, (3) intermediates, and (4) the 5 most susceptible cultivars from which the average numbers of emerged insects ranged from 61.0 to 71.7/replicate.

Plate II shows the contrast in damage and numbers of emerged insects between the most resistant and the most susceptible replicates.

EXPLANATION OF PLATE II

MP10 Sh and X101, the most resistant and the most susceptible sorghum cultivars, respectively, to rice weevils. The progeny that emerged from each sample are shown.

PLATE II

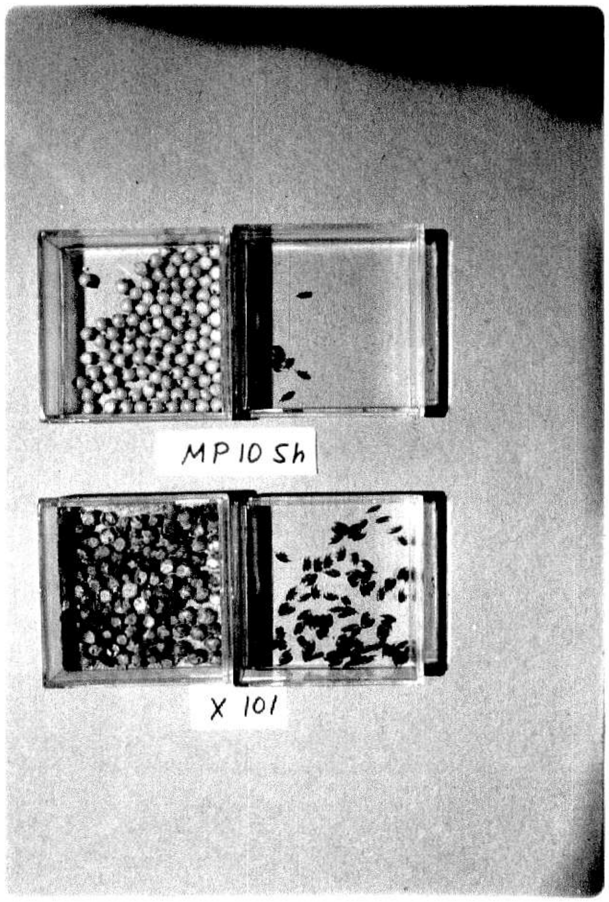

Table 1. Numbers of progeny and the developmental period of rice weevils in 92 sorghum cultivars (100 kernels/sample; 3 replicates) when 10 unsexed adults 7-14 days old per sample (200 total) had free-choice for 5 days oviposition among 20 samples in each test chamber.

Cultivar	Developmental period* (No. days ± 2)		Number of emerged adults			
			Replicate			All replicates
	Range	Avg.**	1	2	3	Avg.
MP10 Sh	29-46	37.5	9	8	7	8.0
65MH 340	29-49	39.0	24	20	34	26.0
C42Y-1	29-48	38.5	26	30	26	27.3
E57	29-43	36.0	31	30	23	28.0
Jumbo L	28-46	37.0	23	37	34	31.3
F65A-1	30-48	39.0	31	28	40	33.0
G814	28-48	38.0	34	33	33	33.3
E57-1	28-51	39.5	24	37	41	34.0
DDES	29-42	35.5	38	33	34	35.0
521	28-47	37.5	33	30	42	35.0
BR54-1	30-52	41.0	43	33	30	35.3
233	29-52	40.5	35	44	30	36.3
880	29-51	40.0	42	42	31	38.3
BR54	30-45	37.5	42	36	38	38.7
F65 a	28-44	36.0	33	46	38	39.0
820	29-48	38.5	37	36	45	39.3
R1019	28-48	38.0	43	44	31	39.3
C42C-1	28-43	35.5	37	44	38	39.7
77A	29-47	38.0	43	33	43	39.7
RS671	29-47	38.0	39	46	38	41.0
ES702	28-46	37.0	40	46	37	41.0
842	29-54	41.5	34	48	43	41.7
7131	28-46	37.0	33	49	44	42.0
760	29-50	39.5	49	38	40	42.3
W851	28-51	39.5	37	45	46	42.7
8681	30-49	39.5	46	48	34	42.7

Table 1 (cont'd).

Cultivar	Developmental period * (No. days ± 2)		Number of emerged adults			
			Replicate			All replicates
	Range	Avg.**	1	2	3	Avg.
8375	29-54	41.5	38	50	41	43.0
180	29-50	39.5	54	42	34	43.3
96	28-43	35.5	42	37	51	43.3
70X	28-48	38.0	35	44	52	43.7
634	29-52	40.5	40	45	46	43.7
F61	28-49	38.5	41	38	53	44.0
E57 a	27-47	37.0	35	46	52	44.3
Dorado M	28-49	38.5	43	46	44	44.3
808	29-46	37.5	41	45	49	45.0
66X	28-51	39.5	45	52	38	45.0
Super 400A	29-51	40.0	42	52	42	45.3
2529	29-47	38.0	38	34	65	45.7
833	30-49	39.5	44	39	54	45.7
Double TX	29-50	39.5	50	35	52	45.7
G522	28-52	40.0	44	47	49	46.7
8417	28-47	37.5	43	45	54	47.3
R1090	28-50	39.0	46	42	55	47.7
Total	28-46	37.0	37	54	53	48.0
511	28-50	39.0	45	52	47	48.0
E59	28-50	39.0	46	45	54	48.3
RS690	28-47	37.5	54	34	57	48.3
GX701	28-51	39.5	55	45	45	48.3
G490	29-51	40.0	53	38	54	48.3
91	28-52	40.0	55	47	43	48.3
C42Y	27-50	38.5	42	45	60	49.0
C42 c	27-46	36.5	46	51	51	49.3
635	29-45	37.0	48	51	49	49.3
729	28-48	38.0	42	51	55	49.3
Dorado E	28-51	39.5	58	42	49	49.7
735	28-51	39.5	55	51	43	49.7
R1029	28-48	38.0	38	57	55	50.0

Table 1 (cont'd).

Cultivar	Developmental period * (No. days ± 2)		Number of emerged adults			
			Replicate			All replicates
	Range	Avg.**	1	2	3	Avg.
412	28-51	39.5	60	45	45	50.0
SG41	28-50	39.0	55	40	56	50.3
516	29-51	40.0	54	41	56	50.3
Y101	28-51	39.5	47	56	50	51.0
691	27-52	39.5	52	50	51	51.0
811A	28-50	39.0	53	54	47	51.3
G820	28-48	38.0	57	45	52	51.3
650	28-52	40.0	53	54	47	51.3
270A	30-51	40.5	63	43	49	51.7
W839	28-45	36.5	52	41	62	51.7
SG40	27-52	39.5	61	46	49	52.0
80	29-51	40.0	51	53	52	52.0
95	28-51	39.5	51	58	47	52.0
Dorado	28-53	40.5	49	53	55	52.3
45	29-50	39.5	49	55	55	53.0
Grain MasterA	28-50	39.0	50	57	53	53.3
Oro	28-46	37.0	63	49	48	53.3
RS628	28-50	39.0	48	58	55	53.7
C42 a	28-47	34.5	61	47	53	53.7
Early Oro	29-48	38.5	56	54	52	54.0
733	28-53	40.5	66	54	44	54.7
R109	28-47	37.5	56	46	64	55.3
RS610	30-47	38.5	52	48	66	55.3
707A	28-50	39.0	64	53	50	55.7
W869	28-49	38.5	50	57	60	55.7
634A	28-50	39.0	62	58	48	56.0
W85	30-46	38.0	55	63	53	57.0
H7043	28-47	37.5	49	58	69	58.7

Table 1 (concluded).

Cultivar	Developmental period * (No. days ± 2)		Number of emerged adults			
			Replicate			All replicates
	Range	Avg.**	1	2	3	Avg.
846	28-50	39.0	62	61	54	59.0
402	29-49	39.0	64	61	55	60.0
RS700	30-53	41.5	63	57	63	61.0
8674	28-51	39.5	72	44	68	61.3
G766 W	28-46	37.0	57	71	64	64.0
GX266	30-50	40.0	66	71	71	69.3
X101	27-54	40.5	67	55	93	71.7

* Calculated from third day of oviposition.

** Average of the minimum and maximum developmental period.

Table 2. Analysis of variance of the emerged progeny rice weevils in 92 sorghum cultivars.

Source of variation	d.f.	Sum of squares	Mean square	F.
Sorghum cultivars	91	24352.324	267.607	5.156**
Experimental error	184	9549.714	51.900	
Total	275	33902.039		

** Significant at 0.05 level of probability.

LSD = 11.5291.

RESISTANCE OF SORGHUM CULTIVARS TO MAIZE WEEVILS

Materials and Methods

Materials and methods were the same as described in the previous rice weevil test except numbers of emerged adult progeny were counted and recorded 3 times a week.

Results and Discussion

The smallest average number of maize weevil progeny emerged from cultivar MP10 Sh (7/replicate) and the largest (72.3/replicate) from cultivar GX266 (Table 3). The average numbers of emerged weevils from the remaining 90 cultivars ranged from 28.3 to 67.0/replicate. Statistical analysis (Table 4) revealed significant differences in the numbers that emerged from different cultivars. Based on a least significant difference (5% level) of 14.59, the sorghum cultivars could be placed in 4 groups according to the degree of resistance: (1) the most resistant cultivar, MP10 Sh, (2) the 30 resistant cultivars from which average numbers of emerged insects ranged from 28.3 to 42.7/replicate, (3) intermediates, and (4) the 9 most susceptible cultivars from which the average numbers of emerged insects ranged from 58.0 to 72.3/replicate.

Plate III shows the contrast in damage and numbers of emerged insects between the most resistant and the most susceptible replicates.

EXPLANATION OF PLATE III

MP10 Sh and GX266, the most resistant and the most susceptible sorghum cultivars, respectively, to maize weevils. The progeny that emerged from each sample are shown.

PLATE III

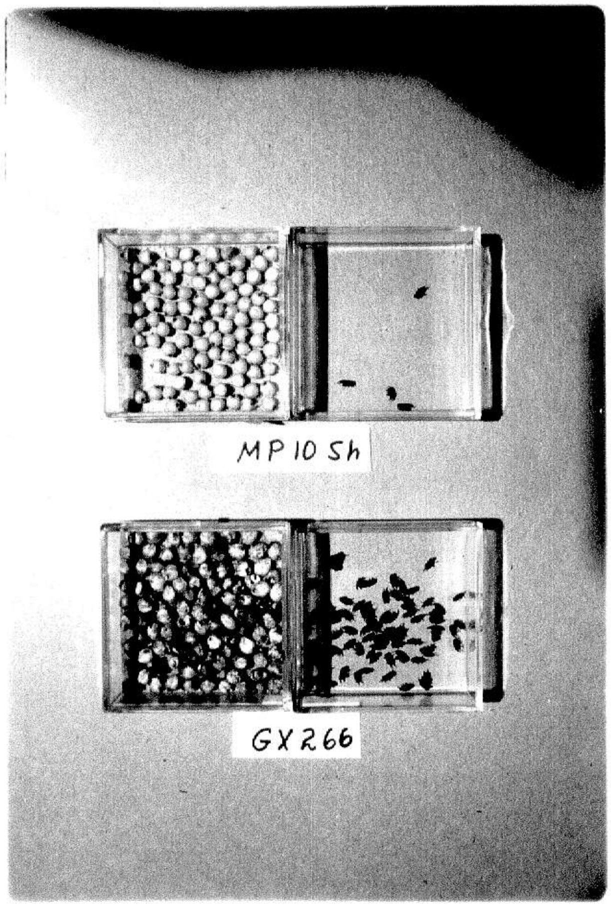

Table 3. Numbers of progeny and the developmental period of maize weevils in 92 sorghum cultivars (100 kernels/sample; 3 replicates) when 10 unsexed adults 7-14 days old per sample (200 total) had free-choice for 5 days oviposition among 20 samples in each test chamber.

Cultivar	Developmental period* (No. days ± 3)		Number of emerged adults			
			Replicate			All replicates
	Range	Avg.**	1	2	3	Avg.
MP10 Sh	29-52	40.5	8	4	9	7.0
E57-1	29-43	36.0	29	27	29	28.3
8375	27-41	34.0	31	37	17	28.3
F65A-1	29-41	35.0	37	27	28	30.7
880	29-50	39.5	35	15	45	31.7
65MH 340	27-45	36.0	37	25	33	31.7
8417	27-43	35.0	42	30	27	33.0
G820	27-41	34.0	40	29	30	33.0
C42Y-1	27-43	35.0	37	32	35	34.7
842	27-43	35.0	31	36	41	36.0
BR54	29-48	38.5	29	31	50	36.7
Y101	27-52	39.5	44	35	31	36.7
511	27-41	34.0	52	35	23	36.7
C42C-1	27-41	34.0	29	45	41	38.3
GX701	27-43	35.0	46	32	38	38.7
80	29-43	36.0	41	45	31	39.0
E57	29-48	38.5	42	26	50	39.3
Dorado	29-48	38.5	49	36	34	39.7
Dorado E	27-45	36.0	43	34	44	40.3
C42Y	29-45	37.0	51	30	43	41.3
G522	29-48	38.5	36	40	48	41.3
ES702	29-45	37.0	26	49	49	41.3
729	29-52	40.5	40	48	36	41.3
Total	27-43	35.0	38	45	41	41.3
Super 400A	29-50	39.5	50	28	47	41.7

Table 3 (cont'd).

Cultivar	Developmental period* (No. days ± 3)		Number of emerged adults			
			Replicate			All replicates
	Range	Avg.**	1	2	3	Avg.
BR54-1	29-55	42.0	49	27	51	42.3
Jumbo L	27-52	39.5	42	43	42	42.3
R1029	27-48	37.5	28	45	54	42.3
E59	27-43	35.0	51	27	50	42.7
F65 a	29-45	37.0	25	55	48	42.7
DDES	27-43	35.0	35	54	39	42.7
C42 a	29-43	36.0	56	41	32	43.0
Early Oro	27-50	38.5	42	38	49	43.0
760	29-48	38.5	38	45	47	43.3
650	27-45	36.0	47	35	49	43.7
RS690	29-48	38.5	45	37	50	44.0
Dorado M	27-43	35.0	44	42	47	44.3
E57 a	27-43	35.0	53	34	46	44.3
G490	29-50	39.5	42	39	52	44.3
G814	29-48	38.5	40	44	50	44.7
735	27-41	34.0	49	38	47	44.7
7131	27-52	39.5	38	35	63	45.3
W839	27-43	35.0	43	40	53	45.3
77A	27-43	35.0	46	39	51	45.3
R1019	27-45	36.0	48	28	60	45.3
412	27-45	36.0	46	54	37	45.7
521	27-50	38.5	44	46	47	45.7
634	27-45	36.0	36	38	64	46.0
733	27-45	36.0	49	36	53	46.0
808	27-43	35.0	44	50	45	46.3
66X	29-48	38.5	54	44	41	46.3
233	27-48	37.5	61	27	52	46.7

Table 3 (cont'd).

Cultivar	Developmental period* (No. days ± 3)		Number of emerged adults			
			Replicate			All replicates
	Range	Avg.**	1	2	3	Avg.
Oro	27-45	36.0	55	34	51	46.7
RS610	29-45	37.0	58	34	48	46.7
270A	29-48	38.5	45	38	57	46.7
91	27-48	37.5	55	45	41	47.0
96	27-48	37.5	57	33	51	47.0
Double TX	29-52	40.5	43	49	50	47.3
691	27-48	37.5	49	38	56	47.7
820	27-50	38.5	51	39	53	47.7
180	29-52	40.5	38	54	51	47.7
634A	27-48	37.5	50	50	43	47.7
C42 c	27-50	38.5	50	48	47	48.3
G766W	27-50	38.5	45	42	59	48.7
RS671	29-45	37.0	50	50	46	48.7
R1090	27-52	39.5	48	64	35	49.0
833	29-52	40.5	55	47	46	49.3
402	29-43	36.0	42	62	45	49.7
R109	27-45	36.0	42	56	53	50.3
811A	29-41	35.0	42	65	46	51.0
95	27-48	37.5	45	62	46	51.0
45	27-43	35.0	52	45	57	51.3
SG41	29-45	37.0	53	58	44	51.7
SG40	27-48	37.5	53	65	38	52.0
W869	27-45	36.0	51	51	56	52.7
RS628	27-45	36.0	55	53	50	52.7
2529	27-48	37.5	67	48	44	53.0
W851	29-45	37.0	56	55	49	53.3
516	27-50	38.5	53	46	62	53.7
F61	27-48	37.5	60	46	60	55.3

Table 3 (concluded).

Cultivar	Developmental period* (No. days ± 3)		Number of emerged adults			
			Replicate			All replicates
	Range	Avg.**	1	2	3	Avg.
H7043	27-41	34.0	63	46	57	55.3
70X	27-41	34.0	55	62	50	55.7
8674	27-43	35.0	56	52	60	56.0
707A	27-48	37.5	48	64	62	58.0
RS700	27-52	39.5	52	50	72	58.0
8681	27-52	39.5	66	45	66	59.0
W85	27-43	35.0	55	62	61	59.3
846	27-48	37.5	68	55	56	59.7
Grain MasterA	29-52	40.5	64	63	57	61.3
635	27-50	38.5	52	55	78	61.7
X101	27-50	38.5	65	71	65	67.0
GX266	27-52	39.5	80	60	77	72.3

* Calculated from third day of oviposition.

** Average of the minimum and maximum developmental period.

Table 4. Analysis of variance of the emerged progeny maize weevils in 92 sorghum cultivars.

Source of variation	d.f.	Sum of squares	Mean square	F.
Sorghum cultivars	91	22265.261	244.673	2.942**
Experimental error	184	15299.558	83.149	
Total	275	37564.820		

** Significant at 0.05 level of probability.

LSD = 14.5929.

RESISTANCE OF SORGHUM CULTIVARS TO LESSER GRAIN BORERS

Materials and Methods

Materials and methods were the same as for rice weevils and maize weevils. Beginning 30 days after the parent adults were removed the numbers of emerged progeny were counted and recorded 3 times per week until no progeny emerged from the cultivar for 7 days.

Results and Discussion

No progeny emerged from cultivars MP10 Sh, ES702, BR54, and W85, and the largest average number was 44.3/replicate from cultivars GX266 and E57a (Table 5). The average number that emerged from the remaining 86 cultivars ranged from 0.3 to 33.7/replicate. Progeny emerged from 92.38% of cultivars in the first and second replicates, and from 93.47% of cultivars in the third replicate. Statistical analysis (Table 6) revealed significant differences in the numbers that emerged from different cultivars. Based on a least significant difference (5% level) of 15.72, the sorghum cultivars could be placed in 3 groups according to the degree of resistance: (1) the 44 most resistant cultivars from which the average numbers of emerged insects ranged from 0.0 to 15.0/replicate, (2) intermediates, and (3) the 9 most susceptible cultivars from which the average numbers of emerged insects ranged from 28.7 to 44.3/replicate.

Plave IV shows the contrast in damage and numbers of emerged insects between the most resistant and the most susceptible replicates.

EXPLANATION OF PLATE IV

MP10 Sh and GX266, the most resistant and the most susceptible sorghum cultivars, respectively, to lesser grain borers. The progeny that emerged from each sample are shown.

PLATE IV

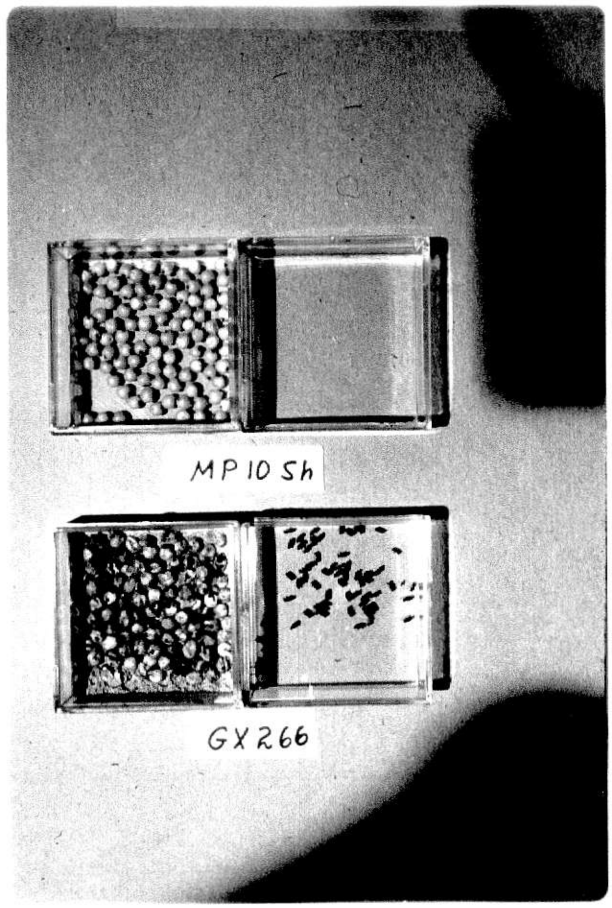

Table 5. Numbers of progeny and the developmental period of lesser grain borers in 92 sorghum cultivars (100 kernels/sample; 3 replicates) when 10 unsexed adults 7-14 days old per sample (200 total) had free-choice for 5 days oviposition among 20 samples in each test chamber.

Cultivar	Developmental period* (No. days ± 3)		Number of emerged adults			
			Replicate			All replicates
	Range	Avg.**	1	2	3	Avg.
MP10 Sh		0.0	0	0	0	0.0
ES702		0.0	0	0	0	0.0
BR54		0.0	0	0	0	0.0
W85		0.0	0	0	0	0.0
C42Y-1		55.0	0	0	1	0.3
E57		52.0	0	1	0	0.3
691		48.0	0	0	2	0.7
E57-1	45-52	48.5	1	3	1	1.7
C42Y	45-50	47.5	6	1	1	2.7
F65 a	48-66	57.0	1	0	12	4.3
R1090	45-57	51.0	4	7	3	4.7
C42C-1	45-59	52.0	2	6	8	5.3
180	45-59	52.0	4	4	9	5.7
C42 c	45-55	50.0	4	0	13	5.7
F65A-1	43-55	49.0	10	1	7	6.0
BR54-1	45-62	53.5	4	11	3	6.0
521	43-62	52.5	11	4	11	8.7
G490	48-66	57.0	21	3	2	8.7
880	45-62	53.5	3	14	9	8.7
Super 400A	45-66	55.5	8	7	11	8.7
Total	45-69	57.0	7	16	3	8.7
W839	43-52	47.5	12	6	8	8.7
8681	45-59	52.0	11	10	6	9.0
W851	45-57	51.0	5	9	16	10.0
833	43-55	49.0	9	8	15	10.7

Table 5 (cont'd).

Cultivar	Developmental period* (No. days ± 3)		Number of emerged adults			
			Replicate			All replicates
	Range	Avg.**	1	2	3	Avg.
8674	43-66	54.5	7	12	14	11.0
SG41	43-59	51.0	2	25	7	11.3
G814	45-64	54.5	3	21	11	11.7
RS671	45-55	50.0	12	8	15	11.7
634A	43-57	50.0	3	12	20	11.7
650	36-55	45.5	1	15	20	12.0
45	45-62	53.5	15	2	20	12.3
233	45-62	53.5	16	14	7	12.3
402	43-69	56.0	11	4	23	12.7
733	43-52	47.5	23	4	12	13.0
C42 a	45-59	52.0	9	6	24	13.0
91	36-64	50.0	7	20	13	13.3
RS628	43-59	51.0	6	31	5	14.0
R1029	45-57	51.0	26	9	7	14.0
RS610	45-62	53.5	12	10	21	14.3
729	41-64	52.5	11	9	23	14.3
Early Oro	45-59	52.0	9	23	12	14.7
820	41-62	51.5	5	30	10	15.0
Double TX	45-66	55.5	15	25	5	15.0
Oro	48-73	60.5	7	27	14	16.0
77A	45-59	52.0	15	16	17	16.0
F61	45-69	57.0	22	20	6	16.0
70X	43-59	51.0	13	12	23	16.0
Grain MasterA	43-64	53.5	5	27	16	16.0
811A	45-62	53.5	20	23	6	16.3
270A	45-66	55.5	11	14	25	16.7
Y101	45-66	55.5	10	20	21	17.0
7131	43-69	56.0	15	27	10	17.3
H7043	43-57	50.0	27	9	21	19.0

Table 5 (cont'd).

Cultivar	Developmental period* (No. days ± 3)		Number of emerged adults			
			Replicate			All replicates
	Range	Avg.**	1	2	3	Avg.
DDES	43-57	50.0	13	27	18	19.3
G820	45-64	54.5	24	15	21	20.0
RS690	43-64	53.5	9	30	21	20.0
Jumbo L	41-64	52.5	21	18	24	21.0
66X	45-62	53.5	13	41	9	21.0
2529	36-62	49.0	33	23	8	21.3
634	48-69	58.5	8	16	40	21.3
65MH 340	45-69	57.0	12	25	27	21.3
8417	45-76	60.5	33	14	17	21.3
842	45-66	55.5	16	21	29	22.0
760	45-69	57.0	32	26	9	22.3
96	36-76	56.0	7	46	15	22.7
R1019	43-64	53.5	24	20	24	22.7
95	36-59	47.5	16	23	30	23.0
R109	45-71	58.0	6	36	28	23.3
8375	43-71	57.0	15	34	21	23.3
G522	45-62	53.5	23	21	30	24.7
W869	45-73	59.0	39	14	22	25.0
707A	43-66	54.5	7	49	19	25.0
516	43-64	53.5	46	12	17	25.0
80	43-76	59.5	6	51	20	25.7
GX701	43-69	56.0	37	21	20	26.0
X101	43-73	58.0	40	12	27	26.3
635	43-78	60.5	37	27	17	27.0
Dorado M	43-76	59.5	18	45	20	27.7
846	45-62	53.5	29	28	26	27.7
Dorado E	45-59	52.0	13	32	39	28.0
511	45-69	52.0	29	43	13	28.3
Dorado	45-64	54.5	23	48	14	28.3

Table 5 (concluded).

Cultivar	Developmental period* (No. days ± 3)		Number of emerged adults			
			Replicate			All replicates
	Range	Avg.**	1	2	3	Avg.
808	45-59	52.0	29	14	43	28.7
RS700	43-69	56.0	24	33	32	29.7
G766W	45-71	58.0	31	38	24	31.0
735	38-78	58.0	36	22	36	31.3
E59	45-73	59.0	25	40	31	32.0
SG40	45-66	55.5	27	42	28	32.3
412	45-69	57.0	33	36	32	33.7
E57 a	45-62	53.5	45	55	33	44.3
GX266	45-69	57.0	54	63	16	44.3

* Calculated from third day of oviposition.

** Average of the minimum and maximum developmental period.

Table 6. Analysis of variance of the emerged progeny lesser grain borers in 92 sorghum cultivars.

Source of variation	d.f.	Sum of squares	Mean square	F.
Sorghum cultivars	91	26290.652	288.908	2.992**
Experimental error	184	17762.984	96.537	
Total	275	44053.636		

** Significant at 0.05 level of probability.

LSD = 15.7239.

RESISTANCE OF SORGHUM CULTIVARS TO RED FLOUR BEETLES

Materials and Methods

Materials and methods were similar to those in previous tests, except that pieces of paper were leaned against the lids containing the samples in testing chamber to serve as bridges for the insects to crawl into and out of the samples. This was not considered necessary for the other species. Each test chamber was infested with 200 10 to 17-day-old adult red flour beetles. Parent beetles were left in chamber for 10 days. This oviposition period was longer than that used for the other insects so that sufficient numbers of progeny were produced to better show differences in resistance. Beginning 50 days after the parents were removed, the numbers of developed progeny adults were counted every 7 days until all had developed.

Results and Discussion

No progeny developed in cultivar MP10 Sh. The largest average number was 11.0/replicate from cultivar E57a (Table 7). The average number that developed in the remaining 90 cultivars ranged from 0.3 to 8.7/replicate. Progeny developed in 89.14% of cultivars in the first replicate, 94.56% of those in the second replicate, and 96.73% of those in the third replicate. Statistical analysis (Table 8) revealed significant differences in the numbers that developed in different cultivars. Based on a least significant difference (5% level) of 3.4, the sorghum cultivars were placed in 3 groups according to the degree of resistance: (1) the 53 most resistant cultivars from which the average numbers of developed insects ranged from 0.0 to 3.3/replicate, (2) intermediates, and (3) the 2 most susceptible cultivars from which the average numbers of developed insects ranged from 8.7 to 11.0/ replicate.

Plate V shows the contrast in damage and numbers of developed insects between the most resistant and the most susceptible replicates.

CORRELATIONS AMONG RESISTANCES OF THE SORGHUM CULTIVARS TO THE 4 INSECT SPECIES

Tables 1, 3, 5, and 7 show that MP10 Sh was the most resistant cultivar to all 4 insect species but other cultivars were resistant to one or more of the insect species and intermediate or susceptible to other species. Statistical analysis of the correlation between resistance of the sorghum cultivars to one species and to each other species (Table 9) shows that at the 0.1 level of probability, there were correlations of 0.67 between rice weevils and maize weevils, 0.47 between lesser grain borers and red flour beetles, 0.41 between rice weevils and lesser grain borers, 0.35 between rice weevils and red flour beetles, 0.28 between maize weevils and red flour beetles, and 0.27 between maize weevils and lesser grain borers. It is evident that there were cultivars which exhibited a similar degree of resistance to the 4 insect species tested. Most of them exhibited a similar degree of resistance to both rice weevils and maize weevils, several cultivars exhibited a similar degree of resistance to both rice weevils and lesser grain borers, to both lesser grain borers and red flour beetles, and to both rice weevils and red

EXPLANATION OF PLATE V

MP10 Sh and E57a, the most resistant and the most susceptible sorghum cultivars, respectively, to red flour beetles. The progeny that developed in each sample are shown.

PLATE V

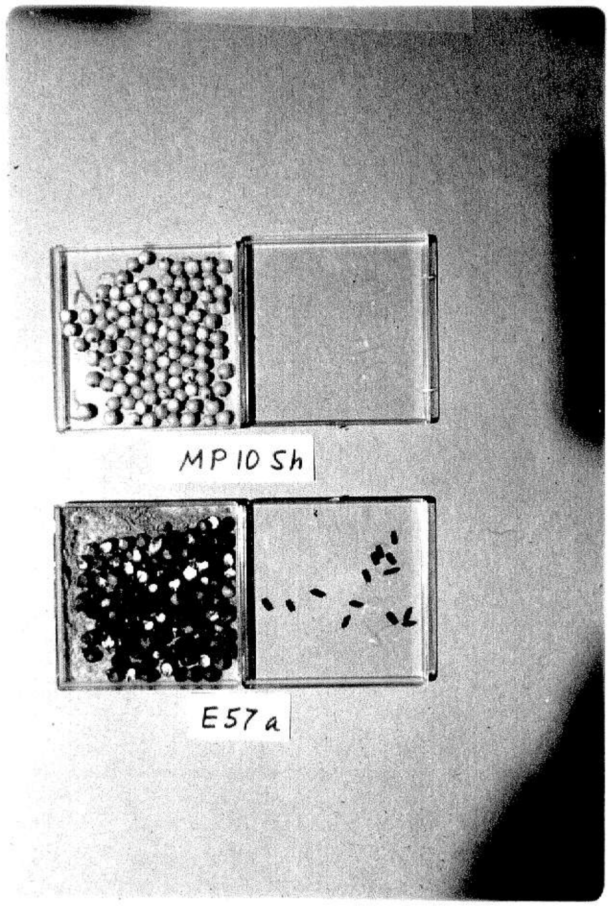

Table 7. Numbers of progeny of red flour beetles in 92 sorghum cultivars (100 kernels/sample; 3 replicates) when 10 unsexed adults 10-17 days old per sample (200 total) had free-choice for 10 days oviposition among 20 samples in each test chamber.

Cultivar	Number of emerged adults: Replicate 1	2	3	All replicates Avg.
MP10 Sh	0	0	0	0.0
BR54	1	0	0	0.3
C42Y	0	1	1	0.7
BR54-1	0	1	1	0.7
C42C-1	0	1	1	0.7
F65 a	0	1	2	1.0
811A	1	1	2	1.3
E57	1	1	2	1.3
E57-1	2	1	2	1.7
F61	2	0	3	1.7
R1019	1	4	0	1.7
180	1	1	3	1.7
RS628	2	1	3	2.0
634	3	1	2	2.0
G820	2	3	1	2.0
820	1	3	2	2.0
G814	2	0	4	2.0
E59	1	1	4	2.0
F65A-1	2	1	3	2.0
65MH 340	2	3	1	2.0
RS700	0	3	3	2.0
880	0	4	2	2.0
Super 400A	1	2	3	2.0
233	1	4	1	2.0
91	3	2	2	2.3
635	3	0	4	2.3

Table 7 (cont'd).

Cultivar	Number of emerged adults			
	Replicate			All replicates
	1	2	3	Avg.
Dorado M	1	3	3	2.3
80	0	5	2	2.3
634A	1	4	3	2.7
691	2	3	3	2.7
C42Y-1	1	5	2	2.7
SG40	1	5	2	2.7
Early Oro	2	3	3	2.7
521	1	6	1	2.7
733	1	3	5	3.0
270A	5	1	3	3.0
Y101	2	2	5	3.0
SG41	5	3	1	3.0
C42 c	1	6	2	3.0
GX701	1	4	4	3.0
2529	2	4	3	3.0
7131	1	4	5	3.3
DDES	1	5	4	3.3
W851	2	6	2	3.3
66X	3	6	1	3.3
W85	1	4	5	3.3
RS610	2	5	3	3.3
Dorado	0	7	3	3.3
8681	1	5	4	3.3
G490	4	1	5	3.3
Double TX	3	4	3	3.3
Total	2	1	7	3.3
Dorado E	3	5	2	3.3
R109	5	5	1	3.7
R1029	2	7	2	3.7

Table 7 (cont'd).

Cultivar	Number of emerged adults			
	Replicate			All replicates
	1	2	3	Avg.
729	0	8	3	3.7
W839	4	2	5	3.7
W869	3	3	5	3.7
707A	2	6	3	3.7
Grain Master A	3	1	7	3.7
H7043	3	4	5	4.0
516	3	4	5	4.0
650	2	5	5	4.0
511	4	3	5	4.0
RS690	4	4	5	4.3
8674	6	2	5	4.3
RS671	6	4	3	4.3
ES702	1	5	7	4.3
760	1	9	4	4.7
735	3	6	5	4.7
412	2	4	8	4.7
846	2	3	10	5.0
G522	3	9	3	5.0
Jumbo L	7	5	3	5.0
G766W	5	7	3	5.0
808	7	5	3	5.0
45	6	6	3	5.0
8417	9	4	2	5.0
R1019	3	5	7	5.0
C42 a	4	4	8	5.3
77A	7	7	2	5.3
X101	7	5	4	5.3
8375	7	4	6	5.7
402	3	7	7	5.7

Table 7 (concluded).

Cultivar	Number of emerged adults			
	Replicate			All replicates
	1	2	3	Avg.
833	6	7	4	5.7
Oro	5	5	7	5.7
96	3	10	4	5.7
GX266	4	11	4	6.3
842	11	5	5	7.0
70X	7	5	10	7.3
95	5	13	8	8.7
E57 a	14	10	9	11.0

Table 8. Analysis of variance of the emerged progeny red flour beetles in 92 sorghum cultivars.

Source of variation	d.f.	Sum of squares	Mean square	F.
Sorghum cultivars	91	874.933	9.614	2.131**
Experimental error	184	829.980	4.510	
Total	275	1704.913		

** Significant at 0.05 level of probability.

LSD = 3.3989.

Table 9. Correlations between resistance of 92 sorghum cultivars to one species of stored-product insect and to other species.

Insect species	Rice weevils	Maize weevils	Lesser grain borers	Red flour beetles
Rice weevils	1.0000**			
Maize weevils	0.6695**	1.0000**		
Lesser grain borers	0.4141**	0.2738**	1.0000**	
Red flour beetles	0.3471**	0.2801**	0.4743**	1.0000**

** Significant at 0.01 level of probability.

flour beetles. Few cultivars exhibited a similar degree of resistance to both maize weevils and lesser grain borers and to both maize weevils and red flour beetles.

CORRELATION BETWEEN HARDNESS OF SORGHUM KERNELS AND RESISTANCE

Materials and Methods

The kernel hardness-testing apparatus (modified from Schoonhoven, 1972) was composed of 2 pieces of plywood joined with a hinge on one end (Plate VI, Fig. 1). The larger piece served as a base. The smaller piece could be moved up and down and had inserted in it a steel cylinder with a diamond crystal cemented in the free end. A weight of 1 or 2 kg was placed in the same location on the plywood above the crystal. The crystal made a diamond-shaped impression (Plate VII, Fig. 1 and 2) in each kernel tested. The longest diagonal of the impression was measured using an ocular micrometer in a binocular microscope. The assumption was that the shorter the diagonal, the harder the kernel.

Five kernels of each of the sorghum cultivars, which had been equilibrated in the rearing room for 15 days, were selected randomly and glued on a small piece of plastic. Each kernel was set under the diamond crystal of the hardness testing apparatus. A 1-kg weight was in place above the cylinder holding the diamond crystal which was carefully lowered against the kernel where it remained for 10 sec. The longest diagonal of the resulting impression was measured and recorded in microns and was used as the index of kernel hardness.

Results and Discussion

The shortest average diagonal length of impression on the surface of 5 kernels was 377.2 microns for cultivar 8417 and the longest was 595.1 microns for cultivar Grain Master A (Table 10). The average diagonal for the remaining 90 cultivars ranged from 383.7 to 575.6 microns. The average numbers of emerged progeny adults of the 4 species of insects for each cultivar in the resistance tests is also shown in Table 10. Statistical analysis for the correlation between hardness of sorghum kernels and relative resistance to stored-product insects indicated a correlation of 0.52, significant at 0.01 level, for maize weevils; 0.41, significant at 0.01 level, for rice weevils; 0.23, significant at 0.05 level, for red flour beetles; and 0.22, significant at 0.05 level, for lesser grain borers. Thus, correlation of hardness and resistance was highest for weevils and lowest for red flour beetles and lesser grain borers although there was a positive correlation for all 4 insect species.

SIZE OF KERNELS AS A FACTOR OF RESISTANCE

Ten kernels of nearly the same size of each of the 92 sorghum cultivars were selected and widest part of each kernel was measured using an ocular micrometer in a binocular microscope. The average width of the smallest and largest kernels of each cultivar along with the thickness of the kernels were used to estimate the size of the kernels and the size was then compared to determine the relationship between size and resistance to insects.

EXPLANATION OF PLATE VI

Fig. 1. Apparatus for testing hardness of sorghum and maize kernels.

Fig. 2. Diamond crystal of kernel hardness testing apparatus cemented on a cylindrical steel rod which is inserted in plywood.

PLATE VI

Fig. 1

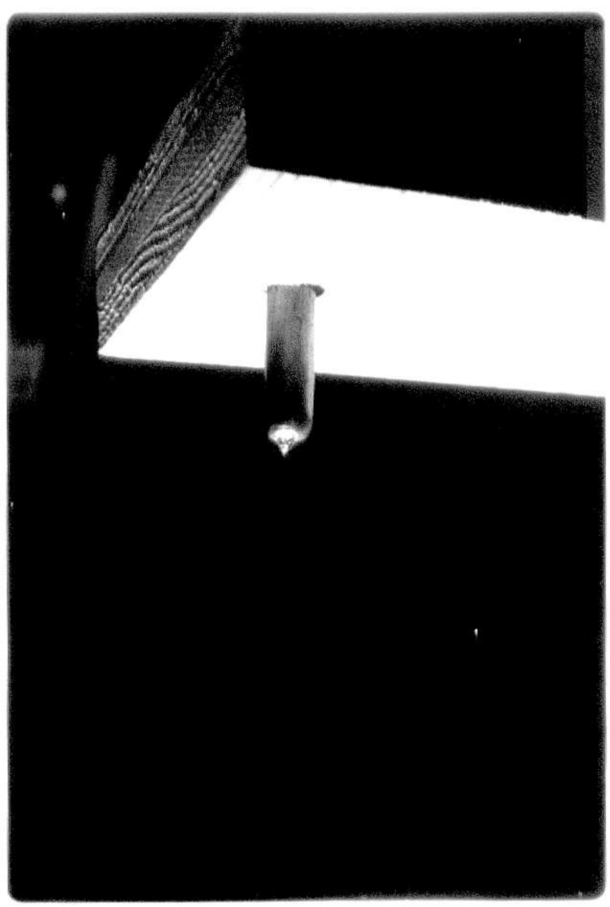

Fig. 2

EXPLANATION OF PLATE VII

Fig. 1. Impression in a harder sorghum kernel, MP10 Sh, the most resistant cultivar, made by the diamond crystal of kernel hardness testing apparatus.

Fig. 2. Impression in a softer sorghum kernel, RS700, the most susceptible cultivar, made by the diamond crystal of kernel hardness testing apparatus.

PLATE VII

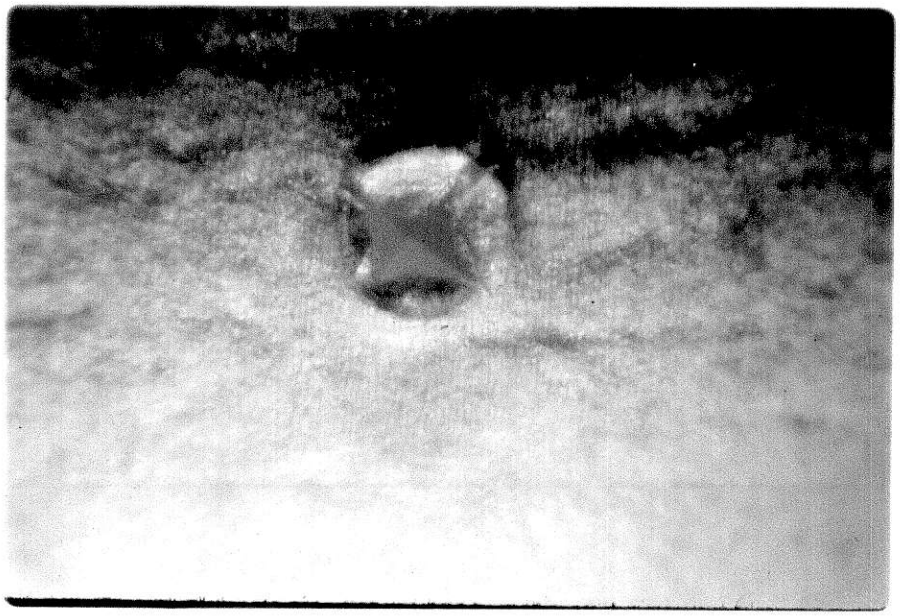

Fig. 1

Fig. 2

Table 10. The length of the longest diagonal of the impression in the surface of 5 sorghum kernels (of each of 92 cultivars) made by a diamond crystal weighted with 1 kg for 10 seconds, and the average numbers of adults which emerged from those cultivars in resistance tests.

Cultivar	Length (microns) of diagonal of diamond impression in sorghum kernel — Kernel 1	2	3	4	5	Average	Average no. emerged adults (of 3 reps)* RW	MW	LGB	RFB
8417	373.98	373.98	357.72	373.98	406.50	377.23	47.33	33.00	21.33	5.00
MP10 Sh	373.98	422.76	406.50	357.72	357.72	383.73	8.00	7.00	0.00	0.00
521	390.24	373.98	390.24	390.24	390.24	386.98	35.00	45.66	8.66	2.66
C42C-1	357.72	341.46	422.76	406.50	406.50	386.98	39.66	38.33	5.33	0.66
C42Y	373.98	357.72	439.02	373.98	390.24	386.98	49.00	41.33	2.66	0.66
Dorado E	373.98	373.98	390.24	406.50	406.50	390.24	49.66	40.33	28.00	3.33
691	373.98	373.98	390.24	422.76	406.50	393.49	51.00	47.66	0.66	2.66
650	373.98	390.24	390.24	406.50	406.50	393.49	51.33	43.66	12.00	4.00
Early Oro	390.24	390.24	406.50	390.24	406.50	396.74	54.00	43.00	14.66	2.66
E57	406.50	422.76	390.24	373.98	406.50	399.99	28.00	39.33	0.33	1.33
E57-1	406.50	406.50	422.76	406.50	373.98	403.24	34.00	28.33	1.66	1.66
R109	406.50	422.76	422.76	390.24	373.98	403.24	55.33	50.33	23.33	3.66
Dorado M	357.72	455.28	406.50	422.76	390.24	406.50	44.33	44.33	27.66	2.33

Table 10 (cont'd).

Cultivar	Length (microns) of diagonal of diamond impression in sorghum kernel						Average no. emerged adults (of 3 reps)*			
	Kernel									
	1	2	3	4	5	Average	RW	MW	LGB	RFB
GX701	422.76	406.50	406.50	373.98	422.76	406.50	48.33	38.66	26.00	3.00
DDES	373.98	390.24	471.54	390.24	406.50	406.50	35.00	42.66	19.33	3.33
C42Y-1	357.72	439.02	390.24	487.80	373.98	409.75	27.33	34.66	0.33	2.66
634	406.50	406.50	373.98	455.28	422.76	413.00	43.66	46.00	21.33	2.00
W839	406.50	422.76	406.50	390.24	439.02	413.00	51.66	45.33	8.66	3.66
W869	406.50	406.50	422.76	406.50	422.76	413.00	55.66	52.66	25.00	3.66
Total	373.98	439.02	390.24	406.50	455.28	413.00	48.00	41.33	8.66	3.33
511	390.24	455.28	390.24	422.76	406.50	413.00	48.00	36.66	28.33	4.00
733	439.02	406.50	406.50	422.76	406.50	416.25	54.66	46.00	13.00	3.00
808	422.76	406.50	422.76	422.76	406.50	416.25	45.00	46.33	28.66	5.00
R1029	487.80	439.02	390.24	373.98	390.24	416.25	50.00	42.33	14.00	3.66
R1019	390.24	471.54	406.50	422.76	406.50	419.50	39.33	45.33	22.66	1.66
8375	406.50	455.28	471.54	373.98	390.24	419.50	43.00	28.33	23.33	5.66
880	390.24	439.02	422.76	455.28	406.50	422.76	38.33	31.66	8.66	2.00

Table 10 (cont'd).

Cultivar	Length (microns) of diagonal of diamond impression in sorghum kernel						Average no. emerged adults (of 3 reps)*			
	Kernel									
	1	2	3	4	5	Average	RW	MW	LGB	RFB
C42a	390.24	455.28	406.50	471.54	390.24	422.76	53.66	43.00	13.00	5.33
BR54	422.76	422.76	406.50	406.50	471.54	426.01	38.66	36.66	0.00	0.33
G522	406.50	455.28	406.50	390.24	471.54	426.01	46.66	41.33	24.66	5.00
SG41	455.28	439.02	390.24	439.02	406.50	426.01	50.33	51.66	11.33	3.00
SG40	439.02	455.28	406.50	439.02	390.24	426.01	52.00	52.00	32.33	2.66
H7043	439.02	422.76	406.50	422.76	439.02	426.01	58.66	55.33	19.00	4.00
233	406.50	373.98	471.54	439.02	455.28	429.26	36.33	46.66	12.33	2.00
96	390.24	439.02	422.76	439.02	455.28	429.26	43.33	47.00	22.66	5.66
66X	439.02	439.02	422.76	422.76	422.76	429.26	45.00	46.33	21.00	3.33
E59	406.50	406.50	422.76	487.80	422.76	429.26	48.33	42.66	32.00	2.00
45	439.02	422.76	390.24	455.28	455.28	432.51	53.00	51.33	12.33	5.00
2529	406.50	487.80	406.50	422.76	439.28	432.56	45.66	53.00	21.33	3.00
G814	439.02	390.24	439.02	455.28	455.28	435.76	33.33	44.66	11.66	2.00
RS671	455.28	439.02	422.76	406.50	455.28	435.76	41.00	48.66	11.66	4.33
E57a	406.50	390.24	390.24	487.80	504.06	435.76	44.33	44.33	44.33	11.00

Table 10 (cont'd).

Cultivar	Length (microns) of diagonal of diamond impression in sorghum kernel						Average no. emerged adults (of 3 reps)*			
	Kernel									
	1	2	3	4	5	Average	RW	MW	LGB	RFB
R1090	406.50	406.50	487.80	422.76	455.28	435.76	47.66	49.00	4.66	5.00
80	439.02	439.02	406.50	471.54	439.02	439.02	52.00	39.00	25.66	2.33
Dorado	471.54	406.50	439.02	406.50	471.54	439.02	52.33	39.66	28.33	3.33
RS628	406.50	455.28	455.28	504.06	373.98	439.02	53.66	52.66	14.00	2.00
91	455.28	471.54	406.50	439.02	439.02	442.27	48.33	47.00	13.33	2.33
Y101	406.50	471.54	504.06	433.76	406.50	444.47	51.00	36.66	17.00	3.00
ES702	455.28	455.28	439.02	439.02	439.02	445.52	41.00	41.33	0.00	4.33
Super 400A	455.28	439.02	422.76	439.02	471.54	445.52	45.33	41.66	8.66	2.00
735	487.80	406.50	520.32	406.50	406.50	445.52	49.66	44.66	31.33	4.66
C42c	390.24	439.02	455.28	520.32	439.02	448.77	49.33	48.33	5.66	3.00
516	471.54	439.02	487.80	406.50	439.02	448.77	50.33	53.66	25.00	4.00
W851	520.32	487.80	422.76	406.50	422.76	452.02	42.66	53.33	10.00	3.33
G490	471.54	406.50	455.28	455.28	471.54	452.02	48.33	44.33	8.66	3.33
BR54-1	455.28	455.28	455.28	439.02	471.54	455.28	35.33	42.33	6.00	0.66
729	455.28	422.76	471.54	455.28	471.54	455.28	49.33	41.33	14.33	3.66

Table 10 (Cont'd).

Cultivar	Length (microns) of diagonal of diamond impression in sorghum kernel						Average no. emerged adults (of 3 reps)*			
	Kernel									
	1	2	3	4	5	Average	RW	MW	LGB	RFB
811A	439.02	439.02	487.80	536.58	390.24	458.53	51.33	51.00	16.33	1.33
Jumbo L	455.28	455.28	487.80	439.02	471.54	461.78	31.33	42.33	21.00	5.00
F65A-1	455.28	504.06	439.02	471.54	439.02	461.78	33.00	30.66	6.00	2.00
180	471.54	406.50	487.80	487.80	455.28	461.78	43.33	47.66	5.66	1.66
70X	422.76	487.80	439.02	530.32	439.02	461.78	43.66	55.66	16.00	7.33
F61	487.80	406.50	504.06	471.54	439.02	461.78	44.00	55.33	16.00	1.66
95	520.32	439.02	406.50	520.32	422.76	461.78	52.00	51.00	23.00	8.66
760	455.28	455.28	504.06	422.76	487.80	465.03	42.33	43.33	22.33	4.66
833	422.76	455.28	520.32	471.54	455.28	465.03	45.66	49.33	10.66	5.66
412	520.32	406.50	406.50	487.80	504.06	465.03	50.00	45.66	33.66	4.66
707A	455.28	487.80	471.54	471.54	439.02	465.03	55.66	58.00	25.00	3.66
635	520.32	471.54	439.02	455.28	455.28	468.28	49.33	61.66	27.00	2.33
65MH 340	520.32	471.54	422.76	422.76	504.16	468.30	26.00	31.66	21.33	2.00
7131	487.80	504.06	439.02	471.54	455.28	471.54	42.00	45.33	17.33	3.33
F65a	487.80	455.28	487.80	455.28	504.06	478.04	39.00	42.66	4.33	1.00

Table 10 (cont'd).

Cultivar	Length (microns) of diagonal of diamond impression in sorghum kernel						Average no. emerged adults (of 3 reps)*			
	Kernel									
	1	2	3	4	5	Average	RW	MW	LGB	RFB
Double TX	471.54	504.06	471.54	455.28	487.80	478.04	45.66	47.33	15.00	3.33
Oro	617.88	471.54	487.80	406.50	406.50	478.04	53.33	46.66	16.00	5.66
842	406.50	504.06	536.58	504.06	471.54	484.54	41.66	36.00	22.00	7.00
634A	487.80	504.06	487.80	487.80	471.54	487.80	56.00	47.66	11.66	2.66
W85	504.06	487.80	520.32	455.28	471.54	487.80	57.00	59.33	0.00	3.33
820	471.54	487.80	536.58	504.06	471.54	494.30	39.33	47.66	15.00	2.00
G820	520.32	439.02	569.10	406.50	569.10	500.80	51.33	33.00	20.00	2.00
77A	617.88	455.28	487.80	520.32	439.02	504.06	39.66	45.33	16.00	5.33
RS690	487.80	439.02	569.10	520.32	504.06	504.06	48.33	44.00	20.00	4.33
846	439.02	487.80	617.88	520.32	455.28	504.06	59.00	59.66	27.66	5.00
402	406.50	520.32	504.06	569.10	536.58	507.31	60.00	49.66	12.66	5.66
X101	617.88	471.54	471.54	522.84	471.54	517.06	71.66	67.00	26.33	5.33
8681	455.28	552.84	487.80	520.32	585.36	520.32	42.66	59.00	9.00	3.33
8674	471.54	471.54	569.10	487.80	617.88	523.57	61.33	56.00	11.00	4.33

Table 10 (concluded).

Cultivar	Length (microns) of diagonal of diamond impression in sorghum kernel						Average no. emerged adults (of 3 reps)*			
	Kernel									
	1	2	3	4	5	Average	RW	MW	LGB	RFB
RS610	504.06	569.10	520.32	504.06	536.58	526.82	55.33	46.66	14.33	3.33
G766W	601.62	601.62	471.54	487.80	504.06	533.32	64.00	48.66	31.00	5.00
270A	569.10	471.54	650.40	406.50	585.36	536.58	51.66	46.66	16.66	3.00
RS700	569.10	601.62	569.10	536.58	536.58	562.59	61.00	58.00	29.66	2.00
GX266	504.06	569.10	650.40	552.84	601.62	575.60	69.33	72.33	44.33	6.33
Grain Master A	536.58	601.62	634.14	585.36	617.88	595.11	53.33	61.33	16.00	3.66

* RW = rice weevil.
MW = maize weevil.
LGB = lesser grain borer.
RFB = red flour beetle.

Rice Weevils

Eight of 11 cultivars in the resistant group had small and medium-sized kernels while the remaining 3 cultivars had medium large and large kernels, as was the case for all 5 cultivars in the most susceptible group. Jumbo L had smaller kernels than any other cultivar and was in the resistant group. MP10 Sh, the most resistant cultivar, had medium-sized kernels as did most cultivars in the resistant group. These results indicated a negative relationship between size of kernels and resistance to rice weevils.

Maize Weevils

About one-half of the 30 cultivars in the resistant group had small and medium-sized kernels, 10 of 15 cultivars in the other half had medium-large kernels, and the remaining 5 cultivars had large kernels. Five of 9 cultivars in the most susceptible group had large kernels; the other 4 cultivars had medium-large kernels. MP10 Sh, the most resistant cultivar, had medium-sized kernels. The results indicated a negative relationship between size of kernels and resistance to maize weevils.

Lesser Grain Borers

Three-fourths of the 44 cultivars in the most resistant group had large and medium-large kernels. All 9 cultivars in the most susceptible group had large and medium-large kernels. Jumbo L, with smallest kernels and DDES, with medium-sized kernels, were intermediates. Dorado, F61, 96, and 811A had the largest kernels of any cultivars and were also intermediate. There appeared to be no relationship between kernel size and resistance to lesser grain borers.

Red Flour Beetles

Only 2 of 92 sorghum cultivars tested were placed in the most susceptible group, while 53 cultivars were placed in the most resistant group. There was no relationship between kernel size and resistance. This species is an external feeder, thus may be affected differently than weevils by kernel size.

COLOR OF KERNELS AS A FACTOR OF RESISTANCE

The color of the kernels of many of the cultivars was difficult to assess because it was masked by field fungi which appeared as black specks. The effect of field fungi on resistance could not be determined because only a small sample of each cultivar was available. The colors recorded were those judged to be the colors had the field fungi not been present.

Seven of 92 cultivars had white kernels, 2 had yellow-white kernels, and the remaining 83 had light-brown to dark-brown kernels. All the colors, except yellow-white, were found in all the resistant and susceptible groups. The 2 yellow-white-kernel cultivars were in the most resistant group in lesser grain borer and red flour beetle tests, in the resistant group in maize weevil tests, and one was in the resistant and one was in the intermediate group in rice weevil tests. Since only 2 yellow-white cultivars were tested it cannot be stated that it is a factor in resistance, and it was concluded that these tests revealed no relationship between color and resistance.

SMOOTHNESS OF KERNELS AS A FACTOR OF RESISTANCE

Twenty sorghum cultivars, which had been designated the 1 most resistant, 9 resistant, 5 intermediate, and 5 most susceptible to rice weevils; 1 most resistant, 7 resistant, 7 intermediate, and 5 most susceptible to maize weevils; 11 most resistant, 6 intermediate, and 3 most susceptible to lesser grain borers; and 12 most resistant and 8 intermediate to red flour beetles, were used for observing the smoothness of kernels. Smoothness of one kernel of each cultivar was observed at the endosperm part on the "back" of kernel (side opposite germ) under a scanning electron microscope at 720X magnification, then compared with kernels of other cultivars in search of an observable relationship between smoothness of kernels and resistance.

Concerning kernel smoothness and rice weevil resistance, it was noted that kernels of cultivar MP10 Sh (Plate VIII, Fig. 1) were not smoother than kernels of cultivars in the most susceptible group (Plate VIII, Fig. 2; and Plate IX, Fig. 1-2). There was no apparent difference in smoothness of kernels among cultivars in different groups, although cultivar E57, a resistant sorghum, was the smoothest kernel found. Therefore, smoothness of sorghum kernels does not appear to be a factor in resistance to rice weevils. Results were similar for maize weevils and lesser grain borers, and there was no apparent relationship between smoothness and resistance to red flour beetles.

EXPLANATION OF PLATE VIII

Fig. 1. Pericarp of kernel of MP10 Sh, the most resistant cultivar to all insect species tested, at 720X.

Fig. 2. Pericarp of kernel of X101, the most susceptible cultivar to rice and maize weevils, at 720X.

PLATE VIII

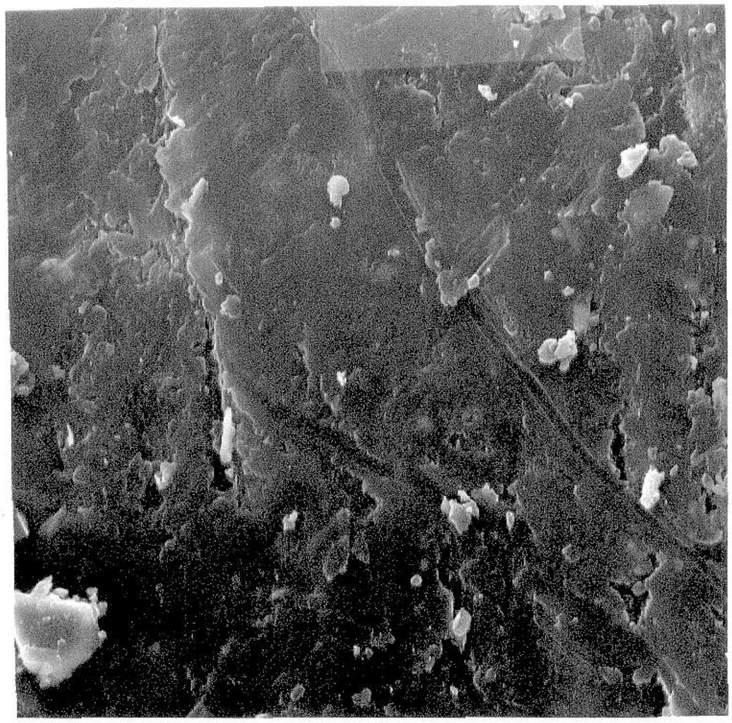

Fig. 1

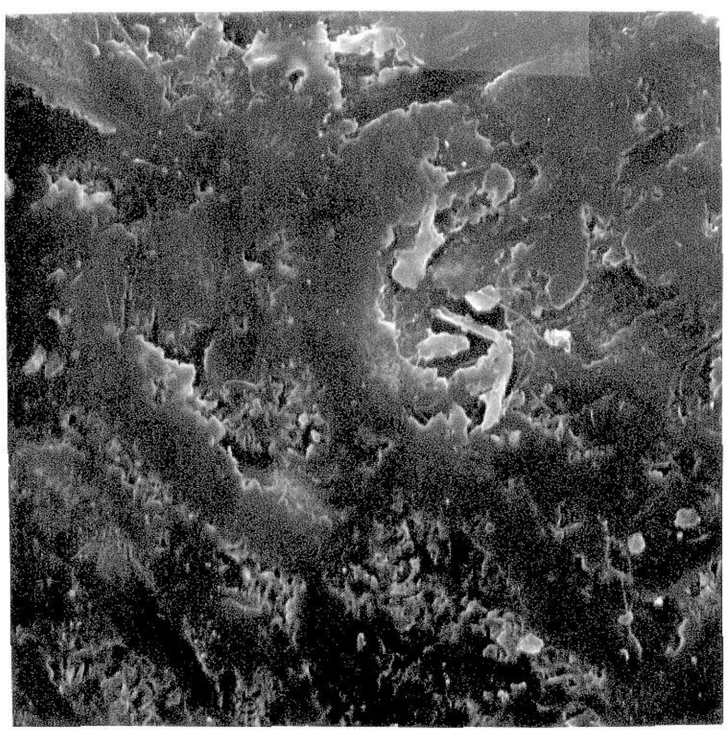

Fig. 2

EXPLANATION OF PLATE IX

Fig. 1. Pericarp of kernel of GX266, the most susceptible cultivar to weevils and lesser grain borers, at 720X.

Fig. 2. Pericarp of kernel of RS700, the most susceptible cultivar to weevils and lesser grain borers, at 720X.

PLATE IX

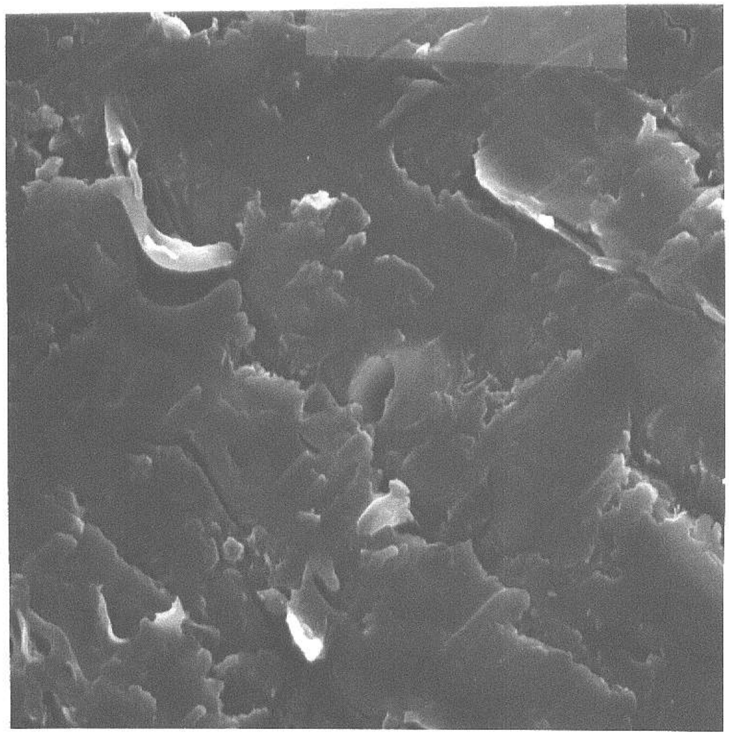

Fig. 1

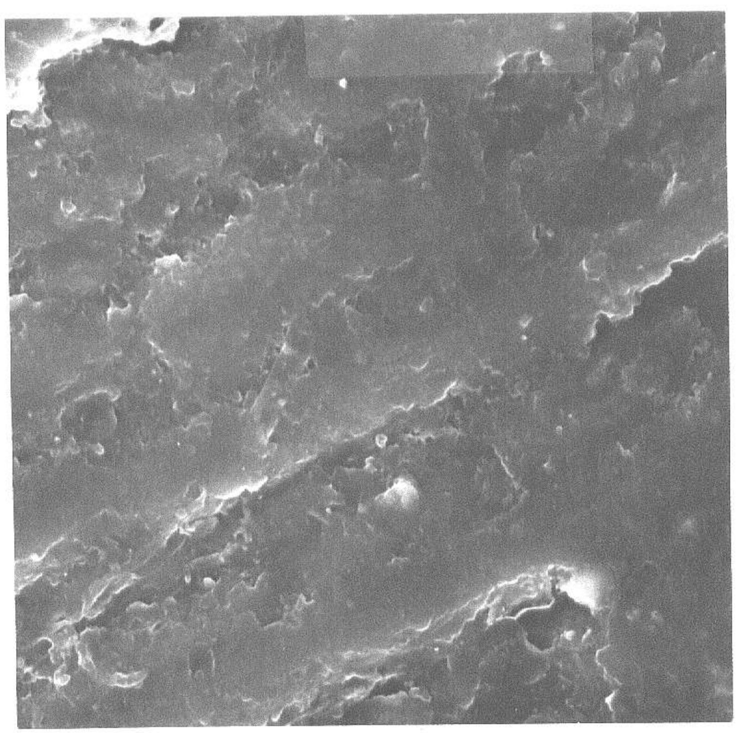

Fig. 2

RESISTANCE OF MAIZE CULTIVARS TO RICE WEEVILS

Materials and Methods

Methods were adapted from previous tests on sorghum. Three replicates of 20 kernels each for each cultivar, which had been equilibrated in the rearing room for 21 days, were selected randomly and placed in 48 x 48 x 6 mm plastic box lids. Nineteen lids were arranged in each testing chamber and infested with 190 7 to 14-day-old adult rice weevils. The parent weevils were left in the chamber for 5 days oviposition. Beginning 25 days after the parent weevils were removed, the numbers of adult progeny were counted and recorded 3 times a week.

Results and Discussion

The smallest average number of progeny rice weevils emerged from cultivar 14 (0.3/replicate) and the largest (10.7/replicate) from cultivar 51 (Table 11). The average number that emerged from the remaining 36 cultivars ranged from 1.7 to 9.7/replicate. Progeny emerged from 97.4% of the cultivars in each replicate. Statistical analysis (Table 12) revealed significant differences in the numbers of emerged progeny from the different cultivars. Based on a least significant difference (5% level) of 3.53, the 38 cultivars could be placed in 3 groups according to the degree of resistance: (1) the 15 most resistant cultivars from which the average numbers of emerged insects ranged from 0.3 to 3.7/replicate, (2) intermediates, and (3) the 8 most susceptible cultivars from which the average numbers of emerged insects ranged from 7.7 to 10.7/replicate.

Plate X shows the contrast in damage and number of emerged insects between the most resistant and the most susceptible replicates.

RESISTANCE OF MAIZE CULTIVARS TO MAIZE WEEVILS

Materials and Methods

Materials and methods were the same as those used for rice weevils.

Results and Discussion

Maize weevils produced more progeny in maize samples than did rice weevils. The smallest average number of progeny maize weevils emerged from cultivar 102 (5.0/replicate) and the largest (23.7/replicate) from cultivar 134 (Table 13). The average number that emerged from the remaining 36 cultivars ranged from 6.3 to 20.3/replicate. Statistical analysis (Table 14) revealed significant differences in the numbers that emerged from the different cultivars. Based on a least significant difference (5% level) of 7.82, the 38 cultivars could be placed in 3 groups according to the degree of resistance: (1) the 19 most resistant cultivars from which the average numbers of emerged insects ranged from 5.0 to 12.7/replicate, (2) intermediates, and (3) the 12 most susceptible cultivars from which the average numbers of emerged insects ranged from 16.0 to 23.7/replicate.

Plate XI shows the contrast in damage and numbers of emerged insects between the most resistant and the most susceptible replicates.

EXPLANATION OF PLATE X

Cultivars 14 and 51, the most resistant and the most susceptible maize to rice weevils. The progeny that emerged from each sample are shown.

PLATE X

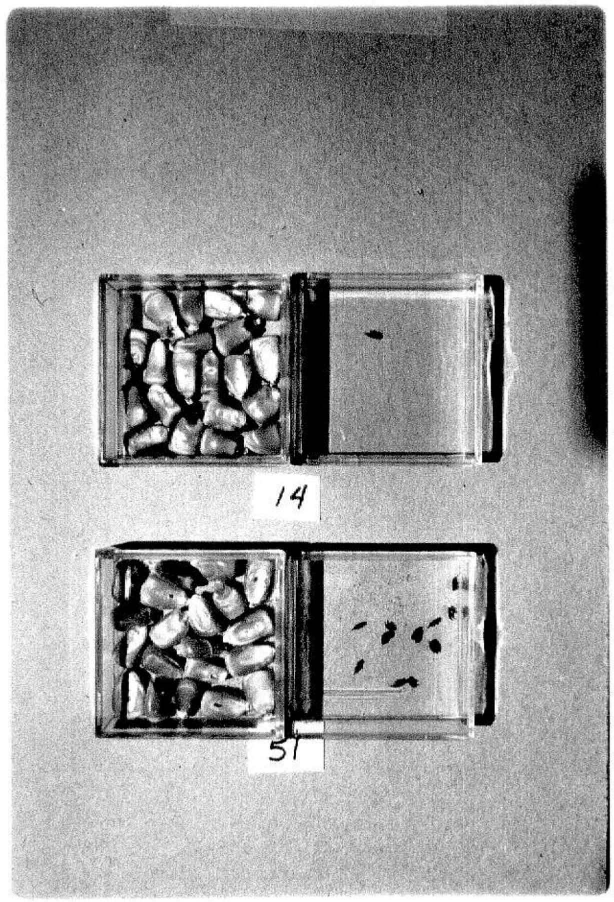

Table 11. Numbers of progeny and the developmental period of rice weevils in 38 maize cultivars (20 kernels/sample; 3 replicates) when 10 unsexed adults 7-14 days old per sample (190 total) had free-choice for 5 days oviposition among 19 samples in each test chamber.

Cultivar	Developmental period* (No. days ± 3)		Number of emerged adults			
			Replicate			All replicates
	Range	Avg.**	1	2	3	Avg.
14		46.0	1	0	0	0.3
101	37-88	62.5	2	2	1	1.7
56	41-55	48.0	1	3	2	2.0
32	37-67	52.0	1	3	3	2.3
105	44-69	56.5	4	2	1	2.3
102	37-60	48.5	1	3	3	2.3
39	39-91	65.0	3	2	4	3.0
36	34-53	43.5	2	5	3	3.3
6	32-79	55.5	3	1	6	3.3
128	34-76	55.0	1	3	6	3.3
125	34-67	50.5	1	3	6	3.3
54	34-88	61.0	5	2	4	3.7
55	32-72	52.0	4	5	2	3.7
127	34-72	53.0	0	5	6	3.7
98	37-69	53.0	3	2	6	3.7
132	34-65	49.5	5	4	3	4.0
131	37-65	51.0	5	6	3	4.7
129	34-74	54.0	3	3	8	4.7
103	39-60	49.5	5	4	5	4.7
89	37-58	47.5	3	5	7	5.0
73	37-83	60.0	6	2	8	5.3
13	32-62	47.0	2	4	10	5.3
86	37-62	49.5	6	5	6	5.7
67	37-58	47.5	8	4	5	5.7
91	37-60	48.5	9	6	3	6.0
74	34-51	42.5	8	3	7	6.0
33	37-69	53.0	7	4	8	6.3

Table 11 (concluded).

Cultivar	Developmental period* (No. days ± 3)		Number of emerged adults			
			Replicate			All replicates
	Range	Avg.**	1	2	3	Avg.
34	37-72	54.5	8	4	8	6.7
65	37-67	52.0	3	9	9	7.0
111	37-72	54.5	7	8	6	7.0
10	37-65	51.0	7	9	7	7.7
94	34-67	50.5	7	7	10	8.0
134	32-67	49.5	7	8	9	8.0
43	32-76	54.0	7	8	10	8.3
92	37-60	48.5	8	8	9	8.3
68	30-65	47.5	6	9	13	9.3
53	30-69	49.5	8	7	14	9.7
51	34-62	48.0	9	9	14	10.7

* Calculated from third day of oviposition.

** Average of the minimum and maximum developmental period.

Table 12. Analysis of variance of the emerged progeny rice weevils in 38 maize cultivars.

Source of variation	d.f.	Sum of squares	Mean square	F.
Maize cultivars	37	664.489	17.959	3.848**
Experimental error	76	354.667	4.666	
Total	113	1019.157		

** Significant at 0.05 level of probability.

LSD = 3.5277.

EXPLANATION OF PLATE XI

Cultivar 102 and 134, the most resistant and the most susceptible maize to maize weevils. The progeny that emerged from each sample are shown.

PLATE XI

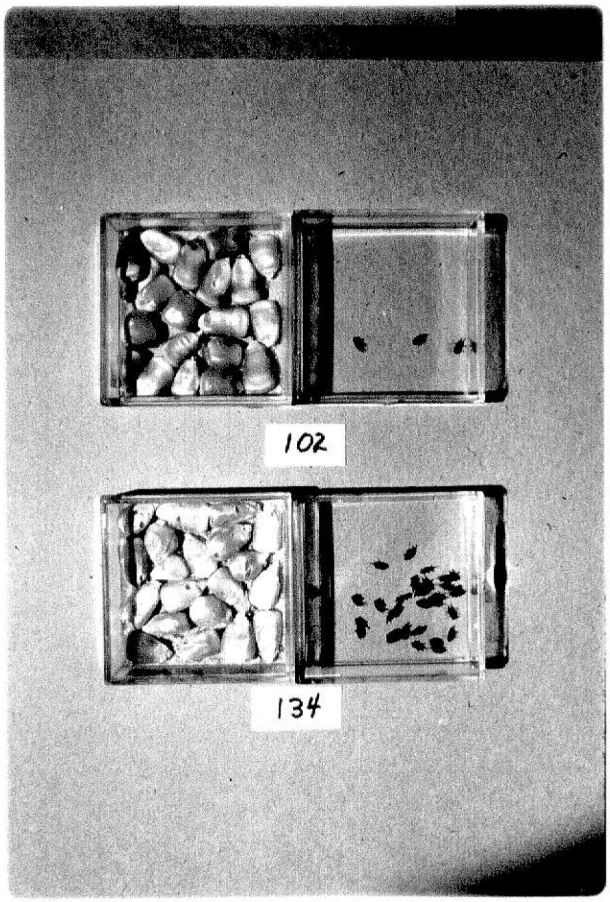

Table 13. Numbers of progeny and the developmental period of maize weevils in 38 maize cultivars (20 kernels/sample; 3 replicates) when 10 unsexed adults 7-14 days old per sample (190 total) had free-choice for 5 days oviposition among 19 samples in each test chamber.

Cultivar	Developmental period* (No. days ± 3)		Number of emerged adults			
			Replicate			All replicates
	Range	Avg.**	1	2	3	Avg.
102	28-56	42.0	5	3	7	5.0
125	35-53	44.0	4	12	3	6.3
105	35-60	47.5	5	11	7	7.7
14	32-56	44.0	8	9	12	9.7
101	30-53	41.5	9	13	7	9.7
56	28-65	46.5	7	13	9	9.7
39	32-51	41.5	5	10	14	9.7
128	32-51	41.5	7	9	14	10.0
10	30-51	40.5	12	13	7	10.7
127	30-49	39.5	8	12	13	11.0
91	30-53	41.5	11	13	9	11.0
54	32-56	44.0	10	13	11	11.3
67	32-65	48.5	12	14	9	11.7
32	32-56	44.0	11	18	7	12.0
89	35-51	43.0	11	12	13	12.0
65	28-65	46.5	18	8	10	12.0
94	35-65	50.0	13	10	14	12.3
73	32-53	42.5	11	10	16	12.3
111	32-60	46.0	15	12	11	12.7
86	35-56	45.5	16	10	14	13.3
98	32-65	48.5	11	20	10	13.7
103	28-65	46.5	19	10	13	14.0
55	30-65	47.5	24	12	7	14.3
132	30-58	44.0	16	15	13	14.7
131	32-60	46.0	13	12	19	14.7
129	32-60	46.0	12	16	16	14.7

Table 13 (concluded).

Cultivar	Developmental period* (No. days ± 3)		Number of emerged adults			
			Replicate			All replicates
	Range	Avg.**	1	2	3	Avg.
43	35-56	45.5	15	16	17	16.0
51	28-51	39.5	13	17	18	16.0
33	30-67	48.5	26	11	11	16.0
74	28-65	46.5	9	11	30	16.7
36	28-67	47.5	32	11	8	17.0
92	30-58	44.0	14	22	15	17.0
34	30-56	43.0	17	17	18	17.3
13	30-50	40.0	14	20	21	18.3
6	28-63	45.5	13	23	19	18.3
53	28-58	43.0	18	18	22	19.3
68	30-60	45.0	23	22	16	20.3
134	30-65	47.5	31	19	21	23.7

* Calculated from third day of oviposition.

** Average of the minimum and maximum developmental period.

Table 14. Analysis of variance of the emerged progeny maize weevils in 38 maize cultivars.

Source of variation	d.f.	Sum of squares	Mean square	F.
Maize cultivars	37	1713.742	46.317	2.022**
Experimental error	76	1740.678	22.903	
Total	113	3454.420		

** Significant at 0.05 level of probability.

LSD = 7.8151.

RESISTANCE OF MAIZE CULTIVARS TO LESSER GRAIN BORERS

Materials and Methods

Methods were adapted from previous tests on sorghum and materials were the same as those used for rice weevils.

Results and Discussion

The smallest average number of progeny lesser grain borers emerged from cultivar 102 (0.7/replicate) and the largest (21.0/replicate) from cultivar 111 (Table 15). The average numbers that emerged from the remaining 36 cultivars ranged from 1.0 to 15.7/replicate. Progeny emerged from 94.7% of the cultivars in the first replicate and from 97.4% of cultivars in the second and third replicates. Statistical analysis (Table 16) revealed significant differences in the numbers of emerged progeny in the different cultivars. Based on a least significant difference (5% level) of 9.46, the maize cultivars could be placed in 3 groups according to the degree of resistance: (1) the 28 most resistant cultivars from which the average numbers of emerged insects ranged from 0.7 to 10.0/replicate, (2) intermediates, and (3) the 7 most susceptible cultivars from which the average numbers of emerged insects ranged from 11.7 to 21.0/replicate.

Plate XII shows the contrast in damage and numbers of emerged insects between the most resistant and the most susceptible replicates.

EXPLANATION OF PLATE XII

Cultivar 102 and 111, the most resistant and the most susceptible maize to lesser grain borers. The progeny that emerged from each sample are shown.

PLATE XII

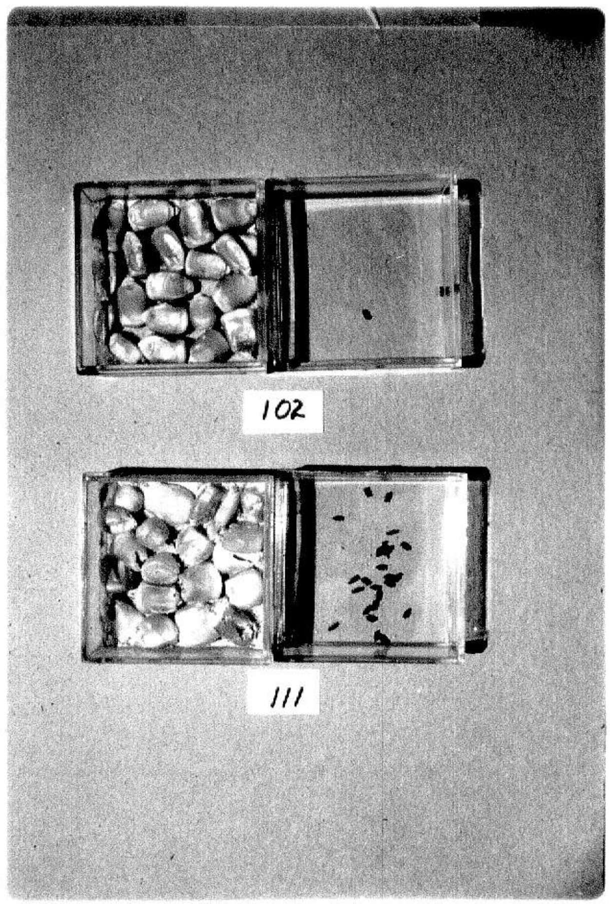

Table 15. Numbers of progeny and the developmental period of lesser grain borers in 38 maize cultivars (20 kernels/sample; 3 replicates) when 10 unsexed adults 7-14 days old per sample (190 total) had free-choice for 5 days oviposition among 19 samples in each test chamber.

Cultivar	Developmental period* (No. days ± 3)		Number of emerged adults			
			Replicate			All replicates
	Range	Avg.**	1	2	3	Avg.
102	56-58	57.0	0	0	2	0.7
74	58-63	60.5	2	1	0	1.0
91	51-77	64.0	0	1	4	1.7
65	58-67	62.5	1	1	5	2.3
94	49-70	59.5	2	2	4	2.7
39	49-74	61.5	2	5	1	2.7
32	56-77	66.5	1	1	7	3.0
43	56-74	65.0	3	8	1	4.0
53	49-70	59.5	10	1	3	4.7
67	51-74	62.5	10	3	1	4.7
34	51-72	61.5	2	8	4	4.7
101	51-72	61.5	1	6	8	5.0
127	51-74	62.5	4	2	9	5.0
105	51-70	60.5	5	8	3	5.3
98	56-77	66.5	2	11	3	5.3
89	49-65	57.0	2	5	9	5.3
56	51-77	64.0	3	4	12	6.3
128	51-74	62.5	4	2	14	6.7
33	49-74	61.5	8	10	2	6.7
6	53-77	65.0	4	7	10	7.0
132	44-65	54.5	2	10	10	7.3
36	49-77	63.0	6	15	1	7.3
10	49-67	58.0	4	14	6	8.0
54	51-79	65.0	2	5	18	8.3
125	49-77	63.0	17	3	5	8.3

Table 15 (concluded).

Cultivar	Developmental period* (No. days ± 3)		Number of emerged adults			
			Replicate			All replicates
	Range	Avg.**	1	2	3	Avg.
131	39-77	58.0	3	13	9	8.3
13	53-72	62.5	12	8	6	8.7
51	44-72	58.0	17	9	4	10.0
103	51-77	64.0	17	8	8	11.0
14	51-77	64.0	3	13	17	11.0
134	51-79	65.0	5	10	18	11.0
55	51-77	64.0	10	20	5	11.7
129	53-77	65.0	4	9	23	12.0
92	46-79	62.5	16	8	14	12.7
86	51-79	65.0	12	12	19	14.3
73	53-77	65.0	31	13	2	15.3
68	49-77	63.0	8	14	25	15.7
111	51-79	65.0	9	29	25	21.0

* Calculated from third day of oviposition.

** Average of the minimum and maximum developmental period.

Table 16. Analysis of variance of the emerged progeny lesser grain borers in 38 maize cultivars.

Source of variation	d.f.	Sum of squares	Mean square	F.
Maize cultivars	37	2251.606	60.854	1.811**
Experimental error	76	2552.670	33.587	
Total	113	4804.277		

** Significant at 0.05 level of probability.

LSD = 9.4640.

RESISTANCE OF MAIZE CULTIVARS TO RED FLOUR BEETLES

Materials and Methods

Methods were adapted from previous tests on sorghum, and materials were the same as those used for rice and maize weevils.

Results and Discussion

Red flour beetles developed in 63.15% of the cultivars in the first replicate, 71.50% of those in the second replicate, and 60.92% of those in the third replicate. No progeny developed in any of the 3 replicates of cultivar 34 and the largest average number was 5.7/replicate in cultivar 111 (Table 17). The average number that developed in the remaining 36 cultivars ranged from 0.3 to 5.3/replicate. Because of the small numbers of insects that developed, the analysis used could not detect significant differences.

Plate XIII shows the contrast in damage and numbers of developed insects between the most resistant and the most susceptible replicates.

EXPLANATION OF PLATE XIII

Maize cultivar 34, in which no red flour beetle progeny developed, and 111, in which the largest number of progeny developed.

PLATE XIII

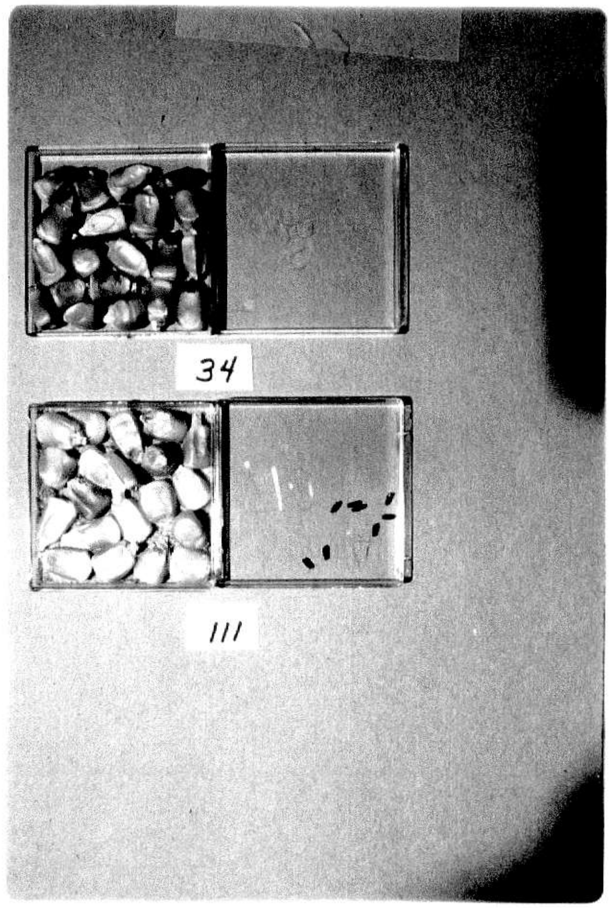

Table 17. Numbers of progeny of red flour beetles in 38 maize cultivars (20 kernels/sample; 3 replicates) when 10 unsexed adults 10-17 days old per sample (190 total) had free-choice for 10 days oviposition among 19 samples in each test chamber.

Cultivar	Number of emerged adults			
	Replicate			All replicates
	1	2	3	Avg.
34	0	0	0	0.0
125	1	0	0	0.3
94	1	0	0	0.3
101	1	0	0	0.3
13	0	1	0	0.3
36	0	0	1	0.3
73	1	1	0	0.7
127	2	0	0	0.7
98	0	2	0	0.7
128	1	0	1	0.7
129	0	0	2	0.7
33	2	0	0	0.7
91	0	2	0	0.7
55	0	2	0	0.7
105	0	2	1	1.0
103	0	3	0	1.0
39	2	0	1	1.0
6	1	0	2	1.0
32	1	2	0	1.0
92	0	1	2	1.0
67	0	2	2	1.3

Table 17 (concluded).

Cultivar	Number of emerged adults			
	Replicate			All replicates
	1	2	3	Avg.
65	2	2	0	1.3
89	4	2	0	2.0
102	2	2	2	2.0
131	1	2	4	2.3
74	1	4	2	2.3
53	2	2	3	2.3
54	0	4	4	2.7
68	0	4	4	2.7
132	3	1	4	2.7
14	6	1	2	3.0
86	0	5	5	3.3
10	1	2	7	3.3
134	1	6	6	4.3
56	4	3	8	5.0
43	3	8	4	5.0
51	4	4	8	5.3
111	4	5	8	5.7

CORRELATIONS AMONG RESISTANCES OF THE MAIZE CULTIVARS TO THE 4 INSECT SPECIES

Tables 11, 13, 15, and 17 show that some maize cultivars were resistant to one or more of the insect species and intermediate or susceptible to other species. Statistical analysis of the correlation between resistance of the 38 maize cultivars to one species and to each of the other species (Table 18) shows that, at the 0.01 level of probability, there was a correlation of 0.60 between rice weevils and maize weevils. At the 0.05 level there were correlations of 0.34 between rice weevils and red flour beetles and 0.33 between lesser grain borers and red flour beetles. There was no correlation between rice weevils and lesser grain borers, maize weevils and lesser grain borers, or maize weevils and red flour beetles. It is evident that most of the 38 maize cultivars exhibited a similar degree of resistance to both rice weevils and maize weevils, several cultivars exhibited a similar degree of resistance to both rice weevils and red flour beetles, and to both lesser grain borers and red flour beetles. Few of them exhibited a similar degree of resistance to both rice weevils and lesser grain borers, to both maize weevils and lesser grain borers, and to both maize weevils and red flour beetles.

Table 18. Correlations between resistance of 38 maize cultivars to one species of stored-product insect and to other species.

Insect species	Rice weevils	Maize weevils	Lesser grain borers	Red flour beetles
Rice weevils	1.0000**			
Maize weevils	0.6043**	1.0000**		
Lesser grain borers	0.2013	0.2778	1.0000**	
Red flour beetles	0.3428*	0.1488	0.3279*	1.0000**

* Significant at 0.05 level of probability.

** Significant at 0.01 level of probability.

CORRELATION BETWEEN HARDNESS OF MAIZE KERNELS AND RESISTANCE

Materials and Methods

Methods were adapted from the previous hardness tests on sorghum. Five kernels each for each of the cultivars which had been equilibrated in the rearing room for 21 days were selected randomly. Each kernel was set under the diamond crystal of the kernel hardness testing apparatus and pressed with a 2-kg weight for 10 seconds. The longest diagonal of the impression was used as the index of kernel hardness.

Results and Discussion

The shortest average length of the diagonal of the impression on the surface of 5 kernels was 552.8 microns for cultivar 55 and the longest was 656.9 microns for cultivar 103 (Table 19). The average diagonal length for the remaining 36 cultivars ranged from 559.3 to 643.8 microns. The average numbers of emerged progeny adults of the 4 species of insects for each cultivar in the resistance tests are also shown in Table 19. Statistical analysis for the correlation between hardness of maize kernels and relative resistance to stored-product insects indicated no correlation significant at 0.05 or 0.01 level. Thus, in this test, the hardness of maize kernels was not an index of resistance to rice weevils, maize weevils, lesser grain borers, or red flour beetles.

Table 19. Length of the longest diagonal of the impression in the surface of 5 maize kernels (of each of 38 cultivars) made by a diamond crystal weighted with 2 kg for 10 seconds, and the average numbers of adults which emerged from those cultivars in resistance tests.

Cultivar	Length (microns) of diagonal of diamond impression in maize kernel						Average no. emerged adults (of 3 reps)*			
	Kernel									
	1	2	3	4	5	Average	RW	MW	LGB	RFB
55	520.32	520.32	552.84	585.36	585.36	552.84	3.66	14.33	11.66	0.66
33	552.84	520.32	552.84	552.84	617.88	559.34	6.33	16.00	6.66	0.66
102	585.36	585.36	552.84	552.84	585.36	572.35	2.33	5.00	0.66	2.00
51	487.80	671.88	585.36	552.84	617.88	572.35	10.66	16.00	10.00	5.33
101	617.88	585.36	585.36	552.84	552.84	578.85	1.66	9.66	5.00	0.33
36	585.36	585.36	552.84	585.36	585.36	578.85	3.33	17.00	7.33	0.33
54	585.36	617.88	552.84	520.32	617.88	578.85	3.66	11.33	8.33	2.66
131	585.36	552.84	478.80	628.92	585.36	578.85	4.66	14.66	8.33	2.33
134	552.84	585.36	617.88	585.36	552.84	578.85	8.00	23.66	11.00	4.33
105	552.84	617.88	650.40	520.32	585.36	585.36	2.33	7.66	5.33	1.00
127	617.88	585.36	552.84	585.36	585.36	585.36	3.66	11.00	5.00	0.66
129	585.36	585.36	617.88	552.84	585.36	585.36	4.66	14.66	12.00	0.66
89	617.88	552.84	585.36	585.36	585.36	585.36	5.00	12.00	5.33	2.00

Table 19 (cont'd).

Cultivar	Length (microns) of diagonal of diamond impression in maize kernel						Average no. emerged adults (of 3 reps)*			
	Kernel									
	1	2	3	4	5	Average	RW	MW	LGB	RFB
111	617.88	617.88	585.36	552.84	552.84	585.36	7.00	12.66	21.00	5.66
32	552.84	585.36	585.36	617.88	617.88	591.86	2.33	12.00	3.00	1.00
125	552.84	650.40	552.84	617.88	585.36	591.86	3.33	6.33	8.33	0.33
13	617.88	617.88	650.40	552.84	520.32	591.86	5.33	18.33	8.66	0.33
86	650.40	585.36	552.84	552.84	617.88	591.86	5.66	13.33	14.33	3.33
43	617.88	552.84	585.36	617.88	585.36	591.86	8.33	16.00	4.00	5.00
14	520.32	650.40	585.36	585.36	650.40	598.36	0.33	9.66	11.00	3.00
56	617.88	585.36	585.36	585.36	617.88	598.36	2.00	9.66	6.33	5.00
98	617.88	552.84	585.36	650.40	585.36	598.36	3.66	13.66	5.33	0.66
65	585.36	628.92	628.92	585.36	585.36	602.78	7.00	12.00	2.33	1.33
39	617.88	585.36	650.40	585.36	585.36	604.87	3.00	9.66	2.66	1.00
128	585.36	617.88	617.88	552.84	650.40	604.87	3.33	10.00	6.66	0.66
132	617.88	617.88	585.36	617.88	585.36	604.87	4.00	14.66	7.33	2.66
53	585.36	617.88	585.36	650.40	585.36	604.87	9.66	19.33	4.66	2.33

Table 19 (concluded).

Cultivar	Length (microns) of diagonal of diamond impression in maize kernel						Average no. emerged adults (of 3 reps)*			
	Kernel									
	1	2	3	4	5	Average	RW	MW	LGB	RFB
34	617.88	650.40	617.88	585.36	585.36	611.37	6.66	17.33	4.66	0.00
94	682.92	650.40	585.36	585.36	552.84	611.37	8.00	12.33	2.66	0.33
67	650.40	617.88	585.36	650.40	585.36	617.88	5.66	11.66	4.66	1.33
68	650.40	617.88	617.88	617.88	585.36	617.88	9.33	20.33	15.66	2.66
91	682.92	585.36	617.88	585.36	650.40	624.38	6.00	11.00	1.66	0.66
10	617.88	617.88	650.40	617.88	617.88	624.38	7.66	10.66	8.00	3.11
92	650.40	617.88	617.88	650.40	585.36	624.38	8.33	17.00	12.66	1.00
73	617.88	617.88	682.92	617.88	585.36	624.38	5.33	12.33	15.33	0.66
74	585.36	585.36	650.40	747.96	585.36	630.88	6.00	16.66	1.00	2.33
6	617.88	715.44	617.88	617.88	650.40	643.89	3.33	18.33	7.00	1.00
103	747.96	650.40	617.88	650.40	617.88	656.90	4.66	14.00	11.00	1.00

* RW = rice weevil.
MW = maize weevil.
LGB = lesser grain borer.
RFB = red flour beetle.

SUMMARY AND CONCLUSIONS

The primary purpose of this study was to evaluate 92 sorghum cultivars and 38 maize cultivars for resistance to rice weevils, maize weevils, lesser grain borers, and red flour beetles. The 92 sorghum cultivars were grown in 1972; 82 were grown in Brown County, Kansas, by the Kansas Agricultural Experiment Station; 8 were obtained from Sorghum Research, DeKalb AgResearch, Inc., Lubbock, Texas; and 2 from Fort Hays Kansas Experiment Station, Hays, Kansas. The 38 maize cultivars were grown in Republic County, Kansas, by the Kansas Agricultural Experiment Station in 1972. Relative hardness of sorghum and maize kernels was measured to determine correlations between hardness and resistance. Tests were conducted in a rearing room with constant $67 \pm 3\%$ RH and temperature of $27 \pm 1^{\circ}C$.

Before testing, grain samples (100 and 20 kernels each of sorghum and maize, respectively) were placed in 48 x 48 x 18 mm plastic boxes with screened lids and placed in the rearing room 15 and 21 days for sorghum and maize, respectively, for moisture content equilibration with the RH of the rearing room.

After equilibration each sample was placed in a 48 x 48 x 6 mm plastic box lid, without screen. Twenty lids with sorghum samples or 19 lids with maize samples were placed in each circular testing chamber (8.5 cm depth x 42 cm diam). The chamber was infested with 10 unsexed adult insects per sample (200 or 190 total) in a free-choice test (7 to 14-day-old rice weevils, maize weevils, or lesser grain borers, or 10 to 17-day-old red flour beetles). These parent insects were allowed 5 days of oviposition, except 10 days for red flour beetles, before they were removed. The samples were returned to the original plastic boxes with screened lids and placed in the rearing room. The emerged progeny were counted beginning 25, 30, or 50 days after removal of parents for weevils, lesser grain borers, or red flour beetles, respectively. Counting ceased when no progeny emerged from any cultivar during 7 days. The number of insects that emerged from each cultivar was used as a measure of relative resistance.

In sorghums, the smallest average number of rice weevil progeny emerged from cultivar MP10 Sh (8.0/replicate) and the largest (71.7) from cultivar X101. Based on the LSD (11.53) for mean numbers of emerged progeny, the cultivars were placed in 4 groups: MP10 Sh, 11 as resistant, 75 as intermediates, and the 5 most susceptible cultivars.

The smallest average number of maize weevil progeny that emerged from sorghum cultivar MP10 Sh (7.0/replicate) and the largest (72.3) from cultivar GX266. Based on the LSD (14.59) for mean numbers of emerged progeny, the cultivars were placed in 4 groups: MP10 Sh, 30 as resistant, 52 as intermediates, and the 9 most susceptible cultivars.

No lesser grain borer progeny emerged from 4 sorghum cultivars, and the largest average number was 44.3/replicate from cultivars GX266 and E57a. Based on the LSD (15.72) for mean numbers of emerged progeny, 44 cultivars were placed in the most resistant group, 39 as intermediates, and 9 in the most susceptible group.

No red flour beetle progeny developed in sorghum cultivar MP10 Sh, and the largest average number was 11.0/replicate in cultivar E57a. Based on the LSD (3.4) for mean numbers of developed progeny, 53 cultivars were placed in the most resistant group, 37 as intermediates, and 2 in the most susceptible group.

The correlation between resistance of 92 sorghum cultivars to one insect species and to another was highest between rice weevils and maize weevils, and lowest between maize weevils and lesser grain borers and between maize weevils and red flour beetles. All correlations were positive.

In maizes, the smallest average number of rice weevil progeny emerged from cultivar 14 (0.3/replicate) and the largest (10.7) from cultivar 51. Based on the LSD (3.53) for mean numbers of emerged progeny, 15 cultivars were placed in the most resistant group, 15 as intermediates, and 8 in the most susceptible group.

The smallest average number of maize weevil progeny emerged from maize cultivar 102 (5.0/replicate) and the largest (23.7) from cultivar 134. Based on the LSD (7.82) for mean numbers of emerged progeny, 19 cultivars were placed in the most resistant group, 7 as intermediates, and 12 in the most susceptible group.

The smallest average number of lesser grain borer progeny emerged from maize cultivar 102 (0.7/replicate) and the largest (21.0) from cultivar 111. Based on the LSD (9.46) for mean numbers of emerged progeny, 28 cultivars were placed in the most resistant group, 3 as intermediates, and 7 in the most susceptible group.

No red flour beetle progeny developed in maize cultivar 34 and the largest average number was 5.7/replicate in cultivar 111. The 38 cultivars could not be grouped statistically into resistant or susceptible groups, because of the small numbers of insects which developed in them.

The correlation between resistance of the 38 maize cultivars to one insect species and to another was highest between rice weevils and maize weevils and lowest between rice weevils and red flour beetles and between lesser grain borers and red flour beetles. There was no correlation between rice weevils and lesser grain borers, between maize weevils and lesser grain borers, and between maize weevils and red flour beetles.

Five kernels each of each of the 92 sorghum cultivars and the 38 maize cultivars were tested for hardness by using a diamond crystal pressed against the kernel for 10 sec with a 1-kg weight for sorghum, and a 2-kg weight for maize. The length of longest diagonal of the diamond-shaped impression in the surface of kernel was used as an index of kernel hardness. Correlation between hardness of sorghum kernels and resistance was highest for weevils, and lowest for lesser grain borers and red flour beetles. There was no correlation between hardness of maize kernels and resistance to any insect species.

Observations were made of other characters of sorghum kernels as possible factors of resistance to stored-product insects. There was a tendency for smaller-kernel cultivars to be more resistant to weevils than the larger-kernel cultivars, but kernel size did not influence resistance to lesser grain borers and red flour beetles. Color and smoothness of pericarp did not appear to influence resistance to any of the insects tested.

Data from these tests indicated that among the sorghum and maize cultivars there were significant differences in resistance to each insect species. For both sorghum and maize there was a higher correlation (0.67, 0.60, respectively) between resistance to rice weevils and resistance to maize weevils than between resistances to other species. This was probably due to the similarity in biology and behavior. Although for every other combination of two insect species, the correlation between resistance to one species and resistance to the other species was positive, they were lower (from no correlation to 0.47). There were greater differences in biology and behavior of these other pairs of species than in the two weevil species when compared with each other. Hardness of sorghum kernels apparently influenced resistance to all insects tested, but hardness of maize kernels did not. The factors responsible for differences in resistance to maize were not apparent in these tests.

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LITERATURE CITED

Ali, Mir Hamed. 1950. Some sorghum insects and their damage to the seeds in the field and storage. Ph.D. Dissertation. Kansas State University, Manhattan.

Back, E. A. 1919. Conserving corn from weevils in the gulf coast states. USDA Farmers Bull. 1029. 36 p.

Breese, M. H. 1960. The infestibility of stored paddy by Sitophilus sasakii and Rhizopertha dominica. Bull. Entomol. Res. 51:599-630.

Cartwright, O. L. 1930. The rice weevil and associated insects in relation to shuck lengths and corn varieties. South Carolina Agr. Exp. Sta. Bull. 266.

Dang, Kamlesh and N. C. Pant. 1965. Relative resistance or susceptibility of several varieties of sorghum to Tribolium castaneum. Indian J. Entomol. 27:245-8.

Davey, P. M. 1964. The susceptibility of sorghum to attack by the weevil Sitophilus oryzae (L.). Int. Congr. Entomol. Proc. London XII. pp. 638-9.

___________. 1965. The susceptibility of sorghum to attack by the weevil Sitophilus oryzae (L.). Bull. Entomol. Res. 56(2):287-97.

Diaz, Gabriel C. 1967. Some relationships of representative races of corn from the Latin America germ plasm seed bank to intensity of infestation by the rice weevil, Sitophilus zeamais Motschulsky (Coleoptera, Curculionidae). Ph.D. Dissertation. Kansas State University, Manhattan.

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

___________. 1958. The breeding of sorghum in East Africa. II. The breeding of weevil resistant varieties. Ibid. 26(10):37-46.

Eden, W. G. 1952. Effect of husk cover of corn on rice weevil damage in Alabama. J. Econ. Entomol. 45(3):543-4.

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

Floyd, E. H. and J. D. Powell. 1958. Some factors influencing the infestation in corn in the field by the rice weevil. J. Econ. Entomol. 51(1):23-6.

Floyd, E. H., A. D. Oliver, and J. D. Powell. 1959. Damage to corn in Louisiana caused by stored grain insects. J. Econ. Entomol. 52(4):612-5.

Hinds, W. E. 1914. Reducing insect injury to stored corn. Alabama Agr. Exp. Sta. Press Bull. 176. 18 p.

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

Hunkapiller, 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.

Kirk, V. M. and A. Manwiller. 1964. Rating dent corn for resistance to rice weevils. J. Econ. Entomol. 57(6):850-2.

Kyle, C. H. 1918. How to reduce weevil waste in southern corn. USDA Farmers Bull. 915. 7 p.

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.

McCain, F. S., W. G. Eden, and D. N. Singh. 1964. A technique for selecting for rice weevil resistance in corn in the laboratory. Crop Sci. 4(1):109-10.

Morrison, E. O. 1964. The effect of particle size of sorghum grain on development of the weevil, Sitophilus zeamais. J. Econ. Entomol. 57(3):390-1.

Munro, J. W. 1966. Pest of Stored Products. London. Hutchinson & Co. (Publishers) LTD.

Painter, R. H. 1951. Insect Resistance in Crop Plants. N. Y. Macmillan Co.

Pant, J. C., S. Kapoor, and N. C. Pant. 1964. Studies on the relative resistance of some maize varieties to Sitophilus oryzae (L.). Indian J. Entomol. 26:434-7.

Rhine, J. 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):280-2.

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.

Rossetto, C. J. 1966. Resistance of varieties of rough rice (paddy) to the Sitophilus zeamais Motschulsky (Coleoptera-Curculionidae). Master's Thesis. Kansas State University, Manhattan.

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): 678-85.

___________. 1966. Effect of four sorghum varieties on the longevity of the lesser rice weevil, Sitophilus oryzae (L.). J. Stored Product Res. 2:75-9.

___________. 1968. Influence of rice variety on oviposition and development of the rice weevil, S. oryzae, and the maize weevil, S. zeamais. Ann. Entomol. Soc. Amer. 61(5):1335-6.

___________, and M. M. Rink. 1965. Some effects of sorghum varieties on the development of a rice weevil, Sitophilus zeamais (Coleoptera, Curculionidae). Ann. Entomol. Soc. Amer. 58(5):763.

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. 15:225-39.

Schoonhoven, Aart van. 1972. Aspects of resistance in corn selection to the maize weevil, Sitophilus zeamais Motschulsky (Coleoptera, Curculionidae). Ph.D. Dissertation. Kansas State University, Manhattan.

Singh, D. N. and F. S. McCain. 1963. Relationship of some nutritional properties of the corn kernel to weevil infestation. Crop Sci. 3(3):259-61.

Singh, S. R., G. G. Kundu, and M. Gupta. 1968. Resistance to stored grain pests in world collection of wheat. I. Comparative susceptibility of the indigenous and exotic wheat varieties to Sitophilus oryzae (L.). Indian J. Entomol. 30(4):299-302.

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

Smith, R. I. 1909. Corn weevil and other grain insects. North Carolina Agr. Exp. Sta. Bull. 203.

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):1222-3.

VanDerSchaaf, Paul, D. A. Wilbur, and R. H. Painter. 1969. Resistance of corn to laboratory infestation of the larger rice weevil, Sitophilus zeamais. J. Econ. Entomol. 62(2):352-5.

Warren, L. O. 1954. Teosinte as a host for stored grain insects. J. Econ. Entomol. 47(4):630-2.

Wilson, P. G. 1912. The corn weevil (Calandra oryzae Linn.). South Carolina Agr. Exp. Sta. Bull. 170.

STUDIES OF RESISTANCE OF 92 SORGHUM AND 38 MAIZE CULTIVARS TO 4 SPECIES OF STORED-PRODUCT INSECTS

by

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The primary purpose of this research was to evaluate resistance to stored-product insects of cultivars of sorghum and maize, most harvested from field trials in Kansas, and to study factors which may cause the resistance. Ninety-two sorghum cultivars and 38 maize cultivars were evaluated for resistance to rice weevils, *Sitophilus oryzae* (L.); maize weevils, *S. zeamaize* (Motsch.); lesser grain borers, *Rhyzopertha dominica* (F.); and red flour beetles, *Tribolium castaneum* (Hbst.). All tests were conducted in a rearing room with 67 ± 3% RH and 27 ± 1°C.

Ten unsexed weevils, lesser grain borers, or red flour beetles per sample (total 200) had free-choice oviposition among 20 tandomly-selected samples (100 kernels each) of sorghum cultivars in each testing chamber. The same number of insects per sample (total 190) had free-choice oviposition among 19 samples (20 kernels each) of maize cultivars in each testing chamber. Three replicate samples of each cultivar were evaluated. Parent insects were left in the chamber for 5 days oviposition, except 10 days for red flour beetles. The average number of emerged progeny per replicate of each insect species was used as the index for resistance.

The sorghum cultivars and maize cultivars were placed in resistant/susceptible groups based on the LSD of the mean numbers of emerged progeny for each insect species. MP10 Sh was the most resistant sorghum cultivar to all insect species tested. The correlation between resistance of sorghum cultivars to one insect species and to another was highest between rice weevils and maize weevils (0.67 and the lowest between maize weevils and lesser grain borers (0.27) and between maize weevils and red flour beetles (0.28). The correlation between resistance of the maize cultivars to one insect species and to another was highest between rice weevils and maize weevils (0.60) and lowest between rice weevils and red flour beetles (0.34) and between lesser grain borers and red flour beetles (0.33). There was no correlation between rice weevils and lesser grain borers, between maize weevils and lesser grain borers, or between maize weevils and red flour beetles.

Hardness of both sorghum and maize kernels was tested by measuring the longest diagonals of diamond-shaped impressions in the surface of kernels made in 10 sec by a diamond crystal weighted with a 1-kg weight for sorghum and a 2-kg weight for maize. Hardness of sorghum kernels was positively correlated with resistance to all insect species tested. The correlation was highest for weevils (0.52 for maize weevils, 0.41 for rice weevils) and lowest for lesser grain borers (0.22) and red flour beetles (0.23). No correlation was found between hardness of maize kernels and resistance to any of the insect species tested.

Size of sorghum kernels appeared to correlate negatively with resistance to weevils, but not to resistance to lesser grain borers or red flour beetles. Color and smoothness of sorghum kernels did not appear to influence resistance to any insect species tested.