FACTORS RELATED TO RICE WEEVIL RESISTANCE IN SORGHUM CULTIVARS

by

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INTRODUCTION

The FAO (1975) ranked sorghum, Sorghum bicolor Pers. fifth in acreage and production among the world's major cereal crops, following wheat, rice, corn and barley. World production of sorghum grain is about 52 million metric tons on approximately 42 million hectares.

In Africa and Asia, where cultivation of the species may have originated, the grain is used as human food, and for livestock feed in the form of grain and fodder (Painter, 1968). Although about three fourths of the world's sorghum acreage is in those countries, they produce only about one third of the grain crop because of insects and mite pests. In those areas the use of insecticides may be uneconomical and hazardous.

Sorghum grain, like other cereal grains, is subject to the attack of a number of insect pests after harvest. Three cosmopolitan species of insects which are important as pests of stored sorghum are the rice weevil, Sitophilus oryzae L., the maize weevil, Sitophilus zeamais Motschulsky, and the Angoumois grain moth, Sitotroga cerealella (Olivier), because they are capable of attacking whole healthy seeds. In warm, tropical climates where much sorghum is grown, these insects may complete a life cycle in less than one month, which means large populations can develop and severe losses may occur in 4 to 6 months of storage. Over 60% kernel damage and 30% loss in weight of sorghum grain resulted from rice weevil infestation after 5 months of storage in a controlled study under tropical conditions in India (Vankatarao et al., 1956).

Detailed discussion on the more common insects injuring stored grain, and effective methods of controlling them have been published, including those by Cotton (1963) in the United States, Munro (1966) in the United Kingdom, Giles (1964) and Doggett (1970) in Africa, and Pruthi and Singh (1963) in India.

Stevens and Mills (1973) compared techniques for screening corn grain varieties for resistance to rice weevils. McCain (1964) developed the 'cafeteria' technique for quick screening of susceptible sorghum cultivars to weevils.

This study was to investigate factors that might cause rice weevil resistance in sorghum grain.

LITERATURE REVIEW

Biology and Ecology of the Rice Weevil

The rice weevil is blackish to reddish with two light-yellowish spots on each of the two hardened front wings (elytra) that cover and protect the membranous flight wings. The pits on the pronotum are rounded and closely compacted.

The female weevil chews a hole through the seed coat and prepares a cavity in the endosperm in which she deposits an egg. She then secretes a gelatinous material to cover the oviposition hole. Frankenfeld (1948) used acid fuchsin to detect infested grain; the dye stained the gelatinous plug cherry red.

The newly-hatched larva tunnels and feeds in the endosperm. During its development a weevil larva sheds its outer skin 4 times. Some have, however, been found to have more than 4 molts (Cotton, 1963). Weevils have 4 distinct developmental stages: egg, larva, pupa and adult. The adult remains inside its kernel for a few days after pupation before chewing an escape hole through the pericarp and emerging.

Howe (1965) found that the minimum temperature for the development of rice weevil was 17°C and the optimum range was between 27-31°C at relative humidity (RH) of 60% and that at this optimum temperature rate of increase was 25-fold.

Eastham and Segrove (1946) found that the durations of the egg and pupal stages of rice weevil were not affected by atmospheric humidity, but that the duration of the larval stages was affected by moisture. They concluded that shortage of moisture acted to dry up the insect thus causing retarded growth and development.

Optimum temperature of 27.5°C found for rice weevil by Dakel et al. (1974) was comparable to what Howe (1965) observed.

Reddy (1950b) found that the interaction of temperature, relative humidity and moisture content of the grain exerted a great influence on the biology of the rice weevil. At 30°C and 99% RH the maximum number of eggs were laid and the highest percentage hatched. He also found that at 13°C or 35°C very few eggs were laid and none of them hatched. Relative humidity of 75% or more was found to be unfavourable for oviposition and no eggs were laid at a RH of 30%.

Reddy (1950b) found oviposition rate and egg-hatching increased with rising humidity. Rice weevils laid no eggs in wheat having a moisture content of 7.4%; eggs were laid in wheat having a moisture content of 9.0%, but failed to hatch. He also found that development, although greatly retarded, was completed in wheat that had a moisture content of 10.2% at 25°, 26.6° and 30°C but not at 32°C. At higher moisture contents the life cycle was completed at 32°C. The shortest period of development was in wheat having a moisture content of 17.6%.

Powell *et al.* showed that rice weevil oviposition might occur in the field on grain with moisture of 65%. Eggs laid at this stage of corn maturity required 9 days for incubation. Complete development from egg to the emergence of the adult required 42 days, and occurred in grain with moisture content of 65% to approximately 25%.

Nutritional Requirements of Stored-Grain Weevils

Nutritional requirements of the rice weevils have not been investigated systematically. Munro (1966) indicated that the weevils had received little attention from entomologists in the developed countries. However, work by D. N. Singh *et al.* (1963) indicated that weevils require a large amount of sugar and starch in their diet for growth and development, which indicates the importance of carbohydrates. He found also that high fat content in the kernels contributed to resistance, and emphasized that there was a strong negative correlation between sugar and fat content. Singh and Gupta (1974) indicated the importance of protein in the nutrition of the weevils and they concluded that higher protein content and higher grain moisture made a variety more susceptible to the weevils.

Chippendale (1972) found that rice weevils survived well on diets containing 72% (w/w) cereal starches, dextrins, amylopectin and glycogen but died prematurely on diets containing amylose, cellulose, inulin, mono- and di-saccharides. He showed that dietary polysaccharides which permitted good survival were feeding stimulants while those which caused early adult death were either feeding deterrents or did not provide suitable physical feeding substances. Chippendale concluded that saturation rather than digestive enzyme tensions was the principal cause of early adult death and that the branched-chain amylopectin portion of the cereal starches in the weevils' natural diet served as both a feeding stimulant and an essential nutrient.

Rhine and Staples (1968) found that 60%-amylose corn reduced both the number of rice weevil adults that emerged and the average developmental period. They also found that although the average weight of adults was reduced on 70%-amylose corn, the number of adults produced was greater than that on either normal or 60%-amylose corn. The 70%-amylose corn, however, reduced survival of larvae of the granary weevil.

Baker and Mabie (1973c) found that casein was very important in the development of the larvae of weevils. An increase in casein concentration beyond 2% was found to increase the survival to adult. They also found that germ oil improved the response of larval growth on an otherwise lipid-free medium (except for cholesterol) through the addition of lipid-soluble growth factors and/or by providing a more suitable physical consistency to the diet.

Baker (1974) compared the utilization of dietary sterols by rice weevil larvae with symbionts and the granary weevil larvae with symbionts. He found that the sterols increased rate of development by 0.1%. He, however, indicated that survival to adult was independent of the cholesterol concentration once the diets contained a threshold amount of 0.005% for granary weevil and between 0.005-0.0% for rice weevils. Also in the same paper, Baker indicated that the larvae of rice weevils utilized B-sitosterol ergosterol, cholesterol, cholesterol acetate and 7-dehydrocholesterol equally well, and growth on diets containing cholesterol was delayed only slightly. Baker concluded that the mycetomal microorganisms in rice weevils apparently could modify different sterols to the benefit of the host insect; in particular, they could assist in the utilization of the fully saturated sterol, cholesterol.

The mycetomal microorganisms associated with the Sitophilus complex were found by Schneider (1956) to provide a nutritional factor (Factor P). Musgrave (1964) also found that the mycetomal microorganisms provided an essential vitamin or mineral or a generalized lipid or lipoprotein (Musgrave and Grinyer, 1968) of value to the host insect, especially when its food supply was nutritionally inadequate.

Factors Related to Resistance in Grains

Researchers have identified several factors which may cause resistance. Selection and breeding for resistance to stored grain insects started years ago.

Ali (1950) surveyed 15 varieties of sorghum and found that only Martin and Cody were favourable for reproduction of rice weevils. Ali, however, associated resistance to the low moisture content of the grains he tested.

The factors that have been suspected to cause resistance in grain are 1) pericarp of the grain, 2) hardness, 3) pericarp thickness, 4) seed size, 5) type of husks, 6) chemical content of grain, and 7) color of grain.

Pericarp

Rout (1973), using 10 sorghum cultivars he had ranked for resistance to S. cerealella, drilled small holes in the kernels and then infested the samples with eggs. He found that the newly-hatched larvae readily entered the holes and developed in all the selections; thus the resistance of the cultivars were destroyed. He also found that sorghum cultivars which were resistant to Tribolium castaneum were rendered susceptible by cracking 10% of the kernels in each sample, or by grinding the kernels into flour. He, however, found an exception in one cultivar where larval development was slow even though the sorghum was in flour form. This suggested resistance factors other than intact pericarp.

White (1975) made cross sections of test sorghum kernels and photographed them using the scanning electron microscope to study the pericarp and seed coat in relation to insect resistance. He measured the thickness of the pericarp and seed coat from the photographs and found that susceptible cultivars had thicker pericarps with conspicuous quantities of starch granules present in the mesocarp layers, while the resistant varieties generally had thinner pericarps and seed coats and few starch granules in the mesocarp. He showed a positive correlation (0.68) between pericarp thickness of sorghum kernels and numbers of progeny produced by maize weevils, but the correlation was only 0.26 for lesser grain borers.

Schoonhoven et al. (1976), using maize weevils and maize, found that damaging the pericarp in various ways made the corn more susceptible to weevils. They used hot water to remove the pericarp, removed the germ from sound kernels with a knife, and also used Plodia interpunctella to remove the germs of kernels. They made pellets from ground whole kernels. After infestation, the above treatments produced more maize weevil progeny than undamaged kernels. They also found that undamaged kernels which were exposed to weevils the second time were more susceptible than kernels which were exposed for the first time. The repeated attack by the insects might have broken down pericarp resistance. They found also that the resistant cultivars yielded more progeny weevils than the susceptible cultivars when the pericarp was damaged. Nwanze et al. (1975) found that cowpeas with smooth seed coats were more susceptible to cowpea weevils than rough varieties.

Hardness

Hardness has been frequently suggested as a factor in resistance of cereal grains to stored-product insects.

Relative hardness was measured by Russell (1966) using a Strong-Scott barley pearler Model 38, and expressed relative hardness in average percent of weight lost through pearling for a given period. The harder the grain the fewer the eggs deposited in it.

Rout (1973) also found a positive relationship between percentage of weight lost by pearling of sorghum samples and the number of maize weevil eggs laid, and the percentage of newly-hatched Angoumois grain moth larvae that survived to adults.

Russell (1966) also found that the adult life span of the rice weevil was shorter in sorghum cultivars with harder kernels.

Maneechoti (1974) measured relative hardness by the penetrating point method. He used the impression made by a diamond point under a 1-kg weight to measure hardness of 92 sorghum cultivars. Maneechoti measured the longest diagonal of the "diamond-shaped" impression. He found no relationship between hardness of 38 cultivars of maize and number of progeny for any of 4 insect species (rice weevil, maize weevil, lesser grain borer, red flour beetle). The penetration of the diamond point might not have measured only hardness. Other factors might have influenced penetration.

White (1975), using the same method as Maneechoti, tested hardness of 24 cultivars of sorghum, which he had evaluated for resistance to maize weevils and lesser grain borers, and found a correlation of 0.65 between hardness and number of maize weevil progeny and 0.61 between hardness and number of lesser grain borer progeny.

In 1965 Davey found a positive correlation between hardness of grain and amount of vitreous endosperm. More damage was done to the softer-grained varieties by weevils. He tested 10 varieties of sorghum.

Seed Size

Seed size was suggested by some researchers as a factor for resistance.

Reddy (1950b) observed that female rice weevils, given a choice, preferred to oviposit on sound kernels rather than halved kernels of wheat. With no choice, however, about the same number of eggs were laid on sound and halved kernels. He found that differences in surface available and weight of grain did not cause the differences in oviposition. He suggested larger size of the grains as an explanation for the preference of sound kernels.

Russell (1962) noticed that when sorghum varieties were mixed, oviposition preference was greatest for the larger seeds.

In 1964 Gundurao and Majumder studied the relation of particle size and the degree of infestation of pulses by Callosobruchus chinensis and concluded that the depth of infestation increased with increase in the size of the seed, which created larger intergranular space.

Ewe (1945) observed that the granary weevil preferred to lay eggs in larger grains of wheat.

Nwanze and Horber (1975) compared relative numbers of three morphological forms of the cowpea weevil reared in a small-seeded variety and a large-seeded variety. Many more "miniature" weevils were produced in the smaller seeds than in larger seeds as the number of eggs/seed increased.

Tight Husks

Ears of maize with long, tight husks have some protection against field infestations of weevils.

Rossetto (1966) was in agreement with Breese (1960) that sound rough rice kernels with well-developed husks, and not attacked by fungus, were not infested by Sitophilus species. He screened 1700 varieties from all over the world for resistance to maize weevil.

Rogers and Mills (1974) screened 1500 sorghum cultivars and found that varieties with tight glumes covering the kernels were almost immune to maize weevils.

Chemical Content of Grains

Eickmeier (1965) showed that high amylose content in corn resulted in resistance to Angoumois grain moth. He also showed that high amylose content was a factor in hardness of seed coat of corn.

In another study, however, Rhine and Staples (1968) found that lesser grain borers were unaffected by high amylose content but rice weevil survival was less. Fewer granary weevil progeny emerged on 70%-amylose corn, and they were smaller than those produced on 60%-amylose corn, which did not appear to affect the weevils.

Su *et al.* (1972) demonstrated that soybean saponin and its calcium salts were highly toxic to rice weevils.

It has been indicated at CIMMYT (1970-71) that as tryptophan and lysine content of grain increased, the number of emerged maize weevil progeny and their weights increased.

Structure of the Mature Seed of Sorghum

The sorghum kernel is a one-seeded fruit known as a caryopsis. The mature seed consists of the embryo, or germ, and the endosperm, both surrounded by a thin cutinous seed coat. The seed is enclosed by an outer covering called a pericarp which is fused to the seed coat. Kernels of sorghum usually weigh about 2.0-3.0 gm per 100 kernels (Wall and Ross, 1970). Miller (1968), however, recorded a weight range of 0.7-6.1 gm per 100 kernels in the world collection of sorghum. The seeds may be white or varying shades of red, yellow, or brown. Hubbard et al. (1950) examined 5 varieties of sorghum and found that the endosperm ranged from between 80.0 to 84.6%, germ from 7.8 and 12.1% and pericarp from 7.3 and 9.3% of the whole kernel.

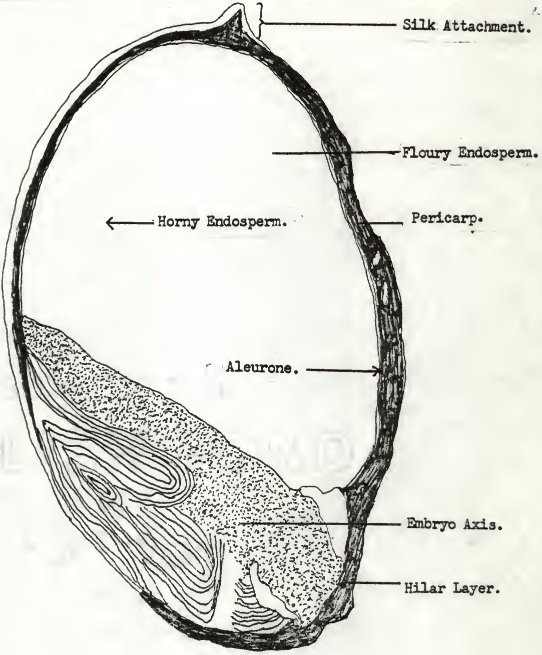
Cowgill (1926) described the sorghum caryopsis to be spherical but always thicker laterally than dorsoventrally.

The mature endosperm consists of cells filled with starch and includes a single outside aleurone layer of cells containing oil and protein. A region of cells containing a dense protein matrix lies beneath the aleurone. The endosperm cells which store starch are further divided into an outer horny region and an inner floury region (Sanders, 1955; Watson et al., 1955). Khalifa (1962) found that the proportion of horny endosperm varies among varieties and even among kernels of the same variety. The horny endosperm is not uniformly thick. It is absent on the surface of the embryo (Wall and Ross, 1970).

The seed coat is composed of a continuous membrane and in some varieties there is a thicker layer of cellular remains (Sanders, 1955). The pericarp is composed of 4 distinct layers: the epidermis, the mesocarp, the cross cell layer, and the tube cell layer (Sanders, 1955).

The mature embryo, which lies at the basal portion of the caryopsis, consists of a primary root, a short axis, the terminal plumule, and the scutellum (Artschwage and McGuire, 1949). The scutellum comprises the bulk of the embryo, almost completely enclosing the embryo axis (Paulson,

Fig. 1. Morphology of grain sorghum kernel (Sander, 1955).


Silk Attachment.
Floury Endosperm.
Horny Endosperm.
Pericarp.
Aleurone.
Embryo Axis.
Hilar Layer.

1969). The plumule is enclosed within a protective sheath known as the coleoptile, and the primary root is sheathed by the coleorhiza. The region between the coleoptile node (second node) and the scutellar plate (first node) commonly is designated as the mesocotyl. The plumule has 4 foliage leaves and the primorlium of a fifth. No axillary buds are present (Chen, 1938; Chi, 1942; Paulson, 1969).

GENERAL MATERIALS AND METHODS

The Kansas strain rice weevil was used for this study. They were cultured on sorghum in the rearing room of the Kansas State University Stored-Product Insects Laboratory at $27\pm1^{\circ}C$ and $67\pm3\%$ RH. Cultures were set up by placing one pint of culture sorghum (12.5-13% moisture content) in a quart jar and infesting the sorghum with about 8 ml of rice weevil adults. The pint jars were covered with a lid containing filter paper treated with Kelthane, and 60-mesh screen.

To remove weevils the appropriate culture jar was taken into the laboratory from the rearing room and the weevils sifted through a 10/in.-mesh sieve into a small aluminum pan, the sides of which were treated with Dupont Teflon (TFE fluorocarbon resin dispersion) that prevented the weevils from crawling out.

I used snout characteristics suggested by Richards (1947) to separate the sexes. The snout of the male is comparatively shorter, rougher and wider than that of the female. I used a Schuco vacuum tweezer aspirator to hold each weevil to be sexed under a binocular microscope.

Professor Harold Hackerott of the Hays, Kansas Agricultural Experiment Station planted all the sorghum cultivars used for the study. The term 'cultivar' is a general term for both 'variety' and 'strain' of sorghum because genetic information about many of the sorghum seeds was not complete.

Before using, the sorghum seeds were placed in a deep freeze for several days to kill any insects which might have been present.

To equilibrate the sorghum seeds at about 13% moisture content after being frozen, I placed the sorghum seeds in the rearing room for 15 days.

TEST I. EVALUATION OF A FREE-CHOICE CHAMBER FOR RESISTANCE TESTING

Introduction

Numbers of progeny are commonly used to determine relative resistance of grain cultivars to weevils. Insect-free samples are exposed to rice weevils and the number of progeny weevils from each sample after a given time is counted.

In 1964 McCain developed a simple laboratory method of evaluating corn resistance to rice weevils. He developed a "cafeteria" or "free-choice" type of circular test chamber. He found that the "cafeteria" method was better when time was a factor than the "no-choice method," because weevils did not have to be sexed.

Stevens (1966) used a rectangular cage of 24 1/2" x 16 3/4" x 3 1/2" dimensions for his free-choice random experiment. He liberated weevils at the empty spaces in the middle and near the sides of the box. He found similar results for the number of weevils on free-choice random and uniform distribution experiments.

White (1975), using one sorghum cultivar in a free-choice test, found that the distribution of adult maize weevils among 20 samples was non-uniform but progeny distribution was uniform. He used a rectangular chamber.

The free-choice test allows the insects to select the samples in which to oviposit.

This study was to further determine the distribution of parent rice weevils and progeny weevils among 20 replicates of a sorghum cultivar and to demonstrate the suitability of the "free-choice" chamber method as a simple method for separation of resistant and susceptible sorghum cultivars.

Materials and Methods

The free-choice chamber used was circular, wooden, and 42 cm in diameter and 8 cm deep. The lid of the chamber had a small hole in the centre through which insects were introduced into the chamber.

I inverted 20 lids (4.8 x 4.8 x 0.7 cm and without screen) of plastic boxes and placed them in the chamber, all equidistant from the centre. I introduced 100 kernels of a culture sorghum (variety unknown) into each of the inverted lids. The chamber lid was taped on and 200 randomly-selected parent rice weevils (10 per sample, sex not determined) were introduced through the hole in the chamber lid. After 5 days I removed the chamber lid under red light (insects were not stimulated by red light) and covered each inverted plastic box lid quickly by placing a plastic box (4.8 x 4.8 x 0.8 cm) on each matching lid containing the kernels. I removed and counted adult rice weevils in each sample. After 28 days I removed and counted progeny weevils weekly from each sample.

Results

The Chi-square statistics calculated for adult and progeny distribution were 35.6 and 3.66, respectively. The parent weevils were randomly distributed among the 20 samples in the test chamber (0.05 significance level) and the progeny distribution was uniform. This conformed with the findings of McCain _et al_. (1964) and White (1975) who used a rectangular chamber.

Table 1. Distribution of ovipositing rice weevils given free choice among 20 samples of the same sorghum variety, and the number of progeny produced (200 parent insects, 5-day oviposition period).

Sample replication	Parent adults	Progeny
1	7	60
2	5	58
3	6	65
4	5	66
5	6	62
6	5	63
7	8	74
8	6	63
9	5	62
10	7	65
11	8	63
12	5	61
13	5	64
14	5	62
15	6	67
16	5	61
17	6	69
18	5	64
19	6	62
20	7	66
Chi-square =	35.6	3.66

Discussion

Since the parent rice weevils were randomly-distributed among the sorghum replicates and the progeny uniformly distributed amont the samples, this method appeared to be valid for testing relative resistance or susceptibility of the sorghum cultivars. McCain et al. (1964) found that the free-choice method had merit in determining resistance to rice weevils since the weevils readily selected the most susceptible hybrids in his cafeteria test.

The free-choice method saves time because weevils need not be sexed and it is a rather quick method for separating susceptible sorghum cultivars from resistant ones. Sexing individuals takes experience and is time-consuming, but is necessary when confining a small number of weevils on small samples in a no-choice test. Mistakes in differentiating sexes can significantly influence the number of progeny from each sample of sorghum. These difficulties and mistakes can be avoided by the use of several samples infested with a 200 randomly-selected unsexed insects.

The free-choice technique may, however, lead to mistaking for susceptible, a resistant cultivar if it is placed near a susceptible cultivar in the chamber; more insects will be attracted to the most susceptible cultivar and there may be an increase in the number of insects feeding on neighbouring samples (VanDerSchaaf, 1969). Also, data from this technique are not easily evaluated statistically because many variable factors are involved. But for preliminary evaluation of large numbers of cultivars it is useful.

TEST II. EVALUATION OF RESISTANCE OF FORTY SORGHUM CULTIVARS TO RICE WEEVIL

Introduction

I tested 40 sorghum cultivars for resistance to rice weevil damage using the free-choice technique. Based on their resistance and susceptibility to rice weevil damage, I selected 8 sorghum cultivars to be tested for factors that might be related to resistance or susceptibility to rice weevil damage.

Materials and Methods

I evaluated 40 sorghum cultivars for resistance to rice weevils in a free-choice test. Included in the 40 sorghums were several CK-60 cultivars which were grown from seeds of a Combine Kafir-60 (CK-60) which had killed weevils in a previous test conducted by White (1975). The original CK-60 later was shown to be contaminated with DDT. The Experiment Station supplied 15 heads of WIRU X KS-56 sorghum samples. I included MP-10 Shallu as a resistant check (MP-10 Shallu was the most resistant sorghum cultivar tested by White in 1975). I also included a cultivar of CK-60 as a susceptible check.

I tested 3 replicates of each sorghum cultivar along with one replicate each of the resistant and susceptible checks.

Each replicate consisted of 100-kernel samples in lids of 4.8 x 4.8 x 0.7 cm plastic boxes. Sixteen samples were selected randomly and placed in each of 6 circular test chambers along with a sample of the resistant check and of the susceptible check.

After equilibrating the samples in the rearing room for 15 days ($27\pm1^{o}C$, $67\pm3\%$ RH), I introduced 180 rice weevils (10 per sample) into each of the test chambers.

I removed adult insects after a 5-day ovipositional period and covered the plastic lids containing the sorghum kernels with matching screened boxes. Progeny weevils were removed daily as they emerged.

Table 2. Mean number of rice weevil (RW) progeny produced in 35 sorghum cultivars (10 parent RW/sample, 18 samples/test chamber; 5-day free-choice oviposition period; 3 replicates; 100-kernel samples).

Cultivar number	Abbreviated pedigree	Mean number of progeny/rep.
772039	CK-60	40.33 a
772012	CK-60	35.00 ab
772013	CK-60	31.33 abc
772016	CK-60	28.67 bcd
772038	CK-60 (suscep. ck.)	27.67 bcde
772008	CK-60	27.67 bcde
772003	CK-60	27.00 bcde
772036	WIRU X KS-56	26.67 bcde
772005	CK-60	24.00 bcdef
772004	CK-60	23.00 bcdef
772015	CK-60	22.67 cdef
772001	CK-60	21.00 cdef
772018	CK-60	20.67 cdef
772010	CK-60	20.67 cdef
772011	CK-60	18.00 def
772009	CK-60	17.67 def
772006	CK-60	17.00 defg
772020	CK-60	16.67 defg
772031	WIRU X KS-56	16.67 defg
772032	WIRU X KS-56	16.33 efg

Table 2 (cont'd).

Cultivar number	Abbreviated pedigree	Mean number of progeny/rep.
772019	CK-60	13.33 fgh
772030	WIRU X KS-56	12.67 fgh
772002	CK-60	12.50 fgh
772007	CK-60	11.33 gh
772017	CK-60	11.30 gh
772040	MP-10 Shallu (Res. ck)	10.67 hi
772014	CK-60	9.67 hi
772033	WIRU X KS-56	9.67 hi
772021	WIRU X KS-56	9.33 hi
772027	WIRU X KS-56	9.33 hi
772022	WIRU X KS-56	8.66 ij
772029	WIRU X KS-56	7.67 j
772025	WIRU X KS-56	5.00 j

Means followed by the same letter are not significantly different.

Alpha level = 0.05 Mean square = 37.76

Analysis of Variance

Source of Variation	d.f.	Sum of Square	Mean Square	F	PR>F
Between cultivars	39	12167.27	311.98	8.26	0.0001
Within cultivars	79	2983.17	37.76		
Corrected total	118	15150.44			

Standard deviation = 6.15 Progeny mean = 15.61

F value not significant at 0.05 alpha level

Results and Conclusion

The WIRU X KS-56 crosses were found to be more resistant than the CK-60 selections. Progeny production varied from 40.33 for the most susceptible cultivar (CK-60, 772039) to 5.00 for the most resistant cultivar (WIRU X KS-56, 772025).

Most of the cultivars from the WIRU X KS-56 crosses, however, were more resistant than either MP-10 or CK-60 cultivars with the exception of a WIRU X KS-56 cross (772036) which was grouped among susceptible cultivars, and 772031, 772032, 772030 which were intermediate.

MP-10 Shallu was the most resistant cultivar in White's test (1975) using maize weevils, with an average number of progeny of 11/sample. Although not the most resistant in the present test, MP-10 yielded an average of 10.67 rice weevil progeny per sample which was similar to White's maize weevils.

TEST III. RELATIVE RESISTANCE OF 100 CULTIVARS OF GREENBUG RESISTANT RP2B SORGHUM TO RICE WEEVILS

Introduction

RP2B is resistant to the greenbug Schizaphis graminum (Rondani). The ARS-USDA, the Nebraska and Kansas Agricultural Experiment Stations and the Mayaguez Institute of Tropical Agriculture, developed it for the use of researchers and commercial breeders in domestic and international breeding programs. The Crop Science Society of America in 1977 registered RP2B.

"RP" stands for regional populations, while "B" stands for fertility and indicates the lines that can be extracted. RP2B also carries the ms_3 gene, for restoring fertility.

Materials and Methods

I evaluated the rice weevil resistance of 100 individual heads of RP2B using the free-choice method. One 100-kernel sample of each head was placed in a plastic test box, frozen to kill possible infestations, then equilibrated in the rearing room (27°C, 67±3% RH) for 15 days. Later 200 (10/sample) randomly-selected, unsexed, adult rice weevils were placed in each chamber containing 20 randomly-selected samples. At the end of 5 days free-choice oviposition, I removed the weevils and covered the sample lids with screened boxes. Progeny counts were made daily after emergence of the first weevil progeny.

Results and Conclusions

Sixty-eight of the 100 RP2B samples each yielded less than 10 progeny rice weevils and only 8 cultivars yielded more than 20. Fifty-eight samples of the RP2B cultivars were more resistant than MP-10 Shallu (a resistant sorghum check) which yielded an average of 10.7 weevils. Range in reproduction was 0-46, with an average of 8.5. The most susceptible cultivar was RP2B-S-8, and the most resistant were RP2B-S-77, RP2B-S-85, and RP2B-S-94.

Since too few kernels of each sample were available, the test was not replicated, and drawing conclusions from the results is not warranted; however, the data indicate that further testing is justified.

Table 3. Rice weevil progeny produced in a free-choice test comparing resistance of 100 heads of RP2B sorghum variety (100/sample; 20 samples/ chamber; 10 parent RW/sample; 5-day oviposition).

Cultivar and head no.	RW progeny per sample	Cultivar and head no.	RW progeny per sample
1. RP2B-S-77	0	15. RP2B-S-57	2
2. RP2B-S-85	0	16. RP2B-S-67	2
3. RP2B-S-94	0	17. RP2B-S-75	2
4. RP2B-S-18	1	18. RP2B-S-83	2
5. RP2B-S-34	1	19. RP2B-S-86	2
6. RP2B-S-88	1	20. RP2B-S-87	2
7. RP2B-S-3	2	21. RP2B-S-22	4
8. RP2B-S-21	2	22. RP2B-S-29	4
9. RP2B-S-27	2	23. RP2B-S-31	4
10. RP2B-S-33	2	24. RP2B-S-37	4
11. RP2B-S-38	2	25. RP2B-S-39	4
12. RP2B-S-48	2	26. RP2B-S-40	4
13. RP2B-S-30	2	27. RP2B-S-46	4
14. RP2B-S-51	2	28. RP2B-S-47	4

Table 3 (cont'd).

Cultivar and head no.	RW progeny per sample	Cultivar and head no.	RW progeny per sample
29. RP2B-S-53	4	61. RP2B-S-42	8
30. RP2B-S-55	4	62. RP2B-S-49	8
31. RP2B-S-60	4	63. RP2B-S-58	8
32. RP2B-S-62	4	64. RP2B-S-82	8
33. RP2B-S-64	4	65. RP2B-S-84	8
34. RP2B-S-68	4	66. RP2B-S-95	8
35. RP2B-S-69	4	67. RP2B-S-100	8
36. RP2B-S-70	4	68. RP2B-S-32	9
37. RP2B-S-76	4	69. RP2B-S-1	10
38. RP2B-S-81	4	70. RP2B-S-15	10
39. RP2B-S-93	4	71. RP2B-S-16	10
40. RP2B-S-96	4	72. RP2B-S-23	10
41. RP2B-S-98	4	73. RP2B-S-43	10
42. RP2B-S-35	4	74. RP2B-S-91	10
43. RP2B-S-97	4	75. RP2B-S-5	12
44. RP2B-S-2	6	76. RP2B-S-6	12
45. RP2B-S-4	6	77. RP2B-S-19	12
46. RP2B-S-9	6	78. RP2B-S-73	12
47. RP2B-S-10	6	79. RP2B-S-92	12
48. RP2B-S-12	6	80. RP2B-S-20	14
49. RP2B-S-14	6	81. RP2B-S-63	14
50. RP2B-S-26	6	82. RP2B-S-66	14
51. RP2B-S-28	6	83. RP2B-S-74	14
52. RP2B-S-54	6	84. RP2B-S-41	15
53. RP2B-S-54	6	85. RP2B-S-52	15
54. RP2B-S-59	6	86. RP2B-S-65	15
55. RP2B-S-61	6	87. RP2B-S-17	16
56. RP2B-S-90	6	88. RP2B-S-44	16
57. RP2B-S-45	7	89. RP2B-S-71	16
58. RP2B-S-11	8	90. RP2B-S-13	18
59. RP2B-S-25	8	91. RP2B-S-30	18
60. RP2B-S-36	8	92. RP2B-S-24	20

Table 3 (cont'd).

Cultivar and head no.		RW progeny per sample	Cultivar and head no.		RW progeny per sample
93.	RP2B-S-7	22	97.	RP2B-S-56	27
94.	RP2B-S-80	25	98.	RP2B-S-78	28
95.	RP2B-S-79	26	99.	RP2B-S-72	30
96.	RP2B-S-99	26	100.	RP2B-S-8	46

TEST IV. EFFECT OF PERICARP ABRASION ON RICE WEEVIL RESISTANCE OF SORGHUM CULTIVARS

Introduction

Undamaged kernel pericarp provides grain with resistance to various insects of stored products. Rout (1973) reported that cracking kernels resulted in resistant kernels becoming susceptible to red flour beetle. Schoonhoven et al. (1972) associated maize weevil resistance in corn with sound pericarp.

Schoonhoven used sand paper to abrade the pericarp of 4 resistant and 4 susceptible dent- or flint-lines of corn. This resulted in reduced maize weevil resistance. More progeny weevils emerged from formerly resistant, damaged kernels of corn than from susceptible, damaged kernels.

This study evaluated how mechanical damage to sorghum pericarp influenced resistance to rice weevils.

Materials and Methods

I selected 7 sorghum cultivars (772040, 772039, 772038, 772024, 772027, 772030 and 772014) from the previous selection study. A small box (11 x 9 x 5 cm) lined with fine sand paper was used for abrasion of kernels of each cultivar. I abraded 100 kernels of each cultivar by rolling the kernels on the sand paper with my gloved fingers for about 5 seconds. I cleaned the abraded kernels using an aspirator. Three replicate 100-kernel samples of each cultivar were abraded. I included 3 replicates of selected sound sorghum kernels of each as a control.

To test each replicate, 6 female and 4 male adult rice weevils were placed in each replicate for a 5-day no-choice ovipositional period. Progeny were counted daily as they emerged.

Results

Numbers of rice weevil progeny produced in abraded kernels (av., 47.9/rep.) were significantly different from those produced in undamaged (av., 19.7).

The overall range in number of progeny weevils was 11.67 for undamaged MP-10 (772040) to 84.00 for damaged WIRU X KS-56 (772024). The undamaged treatments were placed in 3 statistically different groups (susceptible, intermediate and resistant) of the 4 least square difference interaction groupings (Table 4). There were also 3 groupings for the abraded treatments (susceptible, intermediate 1 and intermediate 2).

MP-10 became less resistant after the pericarp was abraded. CK-60-39 retained its susceptibility. WIRU X KS-56-24 lost its resistance after pericarp abrasion; progeny weevil production rose from 14.00 to 84.00; it was then the most susceptible. A cultivar of CK-60 (772014) lost its resistance and became very susceptible; progeny weevil production rose from 12.67 to 56.33; it was the second most resistant with undamaged pericarp but the second most susceptible with abraded pericarp.

Discussion

The increased susceptibility of the abraded kernels in this test supported results of Schoonhoven et al. (1972) who used corn and maize weevils. In most cases, more progeny rice weevils emerged from abraded resistant sorghum cultivars than from undamaged susceptible sorghum cultivars. Damaging the sorghum pericarp might have increased the preference of the female adult weevil to lay more eggs in the kernel. Perhaps roughened surfaces afforded a better grasp for the weevils' tarsi and for the mandibles, thus facilitating the chewing into the kernels. To lay its eggs, the female holds on to each kernel, chews a hole in the kernel and deposits an egg which it later covers with an egg-plug (Cotton, 1963).

Resistant cultivars of sorghum, after the pericarp was abraded, became as susceptible as abraded susceptible cultivars; the susceptibility of previously susceptible cultivars increased slightly after pericarp abrasion. Therefore, undamaged pericarp of the resistant cultivars possessed a factor(s) which was eliminated by abrasion.

Variations in response among the cultivars suggest that factors other than pericarp factor may also be involved. The number of progeny from WIRU X KS-56-24 increased from 13.7 to 84.00 per replicate and CK-60-14 from 12.7 to 56.3. These increases were greater than for the other resistant cultivars. Perhaps the resistant cultivars which did not yield such increases in weevil progeny possessed other factors that influenced their lower progeny yield. The pericarp of WIRU X KS-56-24 and CK-60-14 kernels might have been less tough, thus more damaged by abrasion, than other cultivars.

There was significant variation in the developmental periods of rice weevils between treatments (damaged and undamaged kernels). Developmental

Table 4. Numbers of rice weevil progeny from undamaged and mechanically abraded kernels (3 rep/cultivar; 6 female and 4 male parent RW/rep; 5-day oviposition period; no-choice).

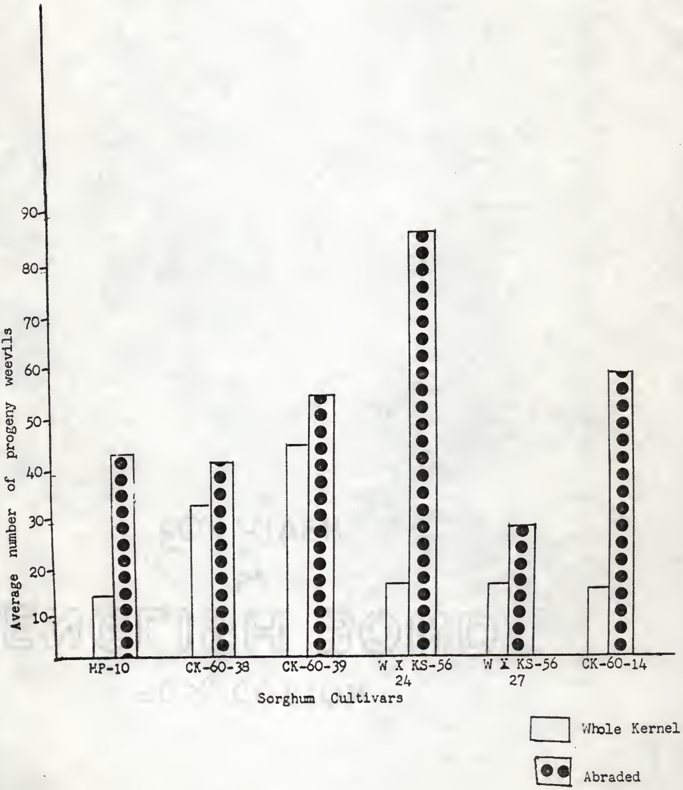
Cultivar	Undamaged pericarp: No. of progeny from undamaged kernels				Avg. dev. period	Abraded pericarp: No. of progeny from damaged kernels				Avg. dev. period
	Replications					Replications				
	1	2	3	Mean		1	2	3	Mean	
772040	12	10	13	12.0	32	38	42	40	40.0	36
772039	40	42	44	42.0	33	49	56	48	52.0	40
772038	30	29	32	30.0	33	35	36	46	39.0	42
772024	10	17	14	14.0	34	86	84	82	84.0	38
772027	13	12	16	13.7	33	30	29	15	24.7	38
772030	12	15	13	13.0	35	32	42	45	39.7	42
772014	10	12	16	13.0	33	55	61	53	56.3	37

Analysis of Variance

Source of variation	Sum of squares	D.F.	Sum of squares	F	$\hat{\text{Alpha}}$
Between cultivars	4424.47	6	737.41	40.70	0.000
Abrasion	8400.84	1	8400.84	463.63	0.000
Interaction	4497.81	6	749.63	41.37	0.000
Within cultivars	507.36	28	18.12		

Table 4 (cont'd).

LSD with 0.05 protection level Significant range 7.1180 Significantly different groupings of means		
Cultivar	Treatment	Means
772024	damaged	84.00 a
772014	damaged	56.33 a
772039	damaged	52.00 a
772039	undamaged	42.00 b
772040	damaged	40.00 b
772030	damaged	39.67 b
772038	damaged	39.00 b
772038	undamaged	30.33 c
772027	damaged	24.67 c
772024	undamaged	14.00 d
772027	undamaged	13.66 d
772030	undamaged	13.33 d
772014	undamaged	12.67 d
772040	undamaged	11.67 d


90
80
70
60
50
40
30
20
10
Average number of progeny weevils
HP-10
CK-60-38
CK-60-39
W X KS-56
24
W X KS-56
27
CK-60-14
Sorghum Cultivars
Whole Kernel
Abraded

periods were longer in damaged kernels than in the undamaged kernels; it was, however, longest in kernels of damaged susceptible cultivars.

More studies should be conducted to find out differences in the pericarp surfaces of the cultivars.

TEST V. EFFECT ON RESISTANCE OF SECOND EXPOSURE OF SELECTED SORGHUM CULTIVARS TO RICE WEEVILS

Introduction

There is little documentation on the effect of repeated exposure of sorghum kernels to weevils on their weevil resistance. Schoonhoven et al. (1972) found that the number of weevil progeny increased significantly on maize lines, as the result of a second infestation with weevils. They found no increase in the numbers of weevil progeny, developmental periods or weights of adult weevils from third through successive infestations.

This study investigated the effect of repeated infestation on the resistance of sorghum kernels to rice weevils.

Materials and Methods

Sorghum cultivars tested were MP-10 Shallu, CK-60-38, CK-60-39, WIRU X KS-56-24 and WIRU X KS-56-27. Each of 10 replicates (100 kernels each) of each of the selected cultivars was placed in a 4.8 x 4.8 x 0.8 cm plastic box with screened lid and infested with 6 female and 4 male rice weevils after 15 days of equilibration in the rearing room (27°C, 67±3% RH). I removed the weevils after a 5-day no-choice ovipositional period.

I removed obviously-damaged kernels from each sample 21 days after infestation and froze the remainder. I later radiographed the kernels using a grain inspection X-ray unit. Using the radiograph for reference, I selected and removed the internally damaged kernels.

I prepared 3 100-kernel replicates of each cultivar, using undamaged kernels previously exposed to weevils and also 3 replicates of the same sorghum cultivars not previously exposed to weevils. I equilibrated the replicates for 2 weeks in the rearing room (27°C, 67±3% RH). I later infested each replicate with 6 female and 4 male rice weevils for a 5-day no-choice ovipositional period.

Emerged progeny weevils were removed, counted and weighed daily. Weights were determined using a Mettler balance; each progeny weevil was weighed in a No. 5 gelatin capsule.

Results

More progeny weevils emerged from exposed kernels than sound kernels (Table 5). The interaction between cultivar and previous exposure to weevils was significant.

For all cultivars and both treatments, the weevil progeny means were ranked and 6 significantly different groups were formed. None of the means for unexposed kernels were in the most susceptible group and none of the means for previously exposed kernels were in the most resistant group.

There were no significant differences between sound kernels and exposed kernels for larval developmental period or average live weight of progeny weevils within cultivars.

Table 5. Rice weevil development on 5 sorghum cultivars. Sound kernels and weevil-exposed kernels tested in 3 replicates each (6 female and 4 male parent RW/rep, 5-day ovipositional period; no-choice).

Cultivar	Treatment	Avg. no. of progeny	Avg. dev. period	Avg. live weight
MP-10 (Res. ck)	Sound kernel	9.67	30.60	1.860
	Exposed kernel	21.00	29.90	1.900
CK-60-38	Sound kernel	27.67	32.00	1.956
	Exposed kernel	45.00	32.32	1.950
CK-60-39	Sound kernel	36.00	34.8	2.000
	Exposed kernel	47.00	32.6	2.000
WIRU X KS-56-24	Sound kernel	10.67	34.10	1.905
	Exposed kernel	31.67	32.30	1.900
WIRU X KS-56-27	Sound kernel	11.33	34.60	1.950
	Exposed kernel	23.67	33.84	1.947

Analysis of Variance

Source of variation	Sum of squares	D.F.	Mean square	F	$\hat{\text{Alpha}}$
Between cultivars	3334.47	4	833.62	115.78	0.000
Repeated infestation	1598.70	1	1598.70	222.05	0.000
Interaction	115.80	4	28.95	4.021	0.015
Within cultivars	144.00	20	7.20		

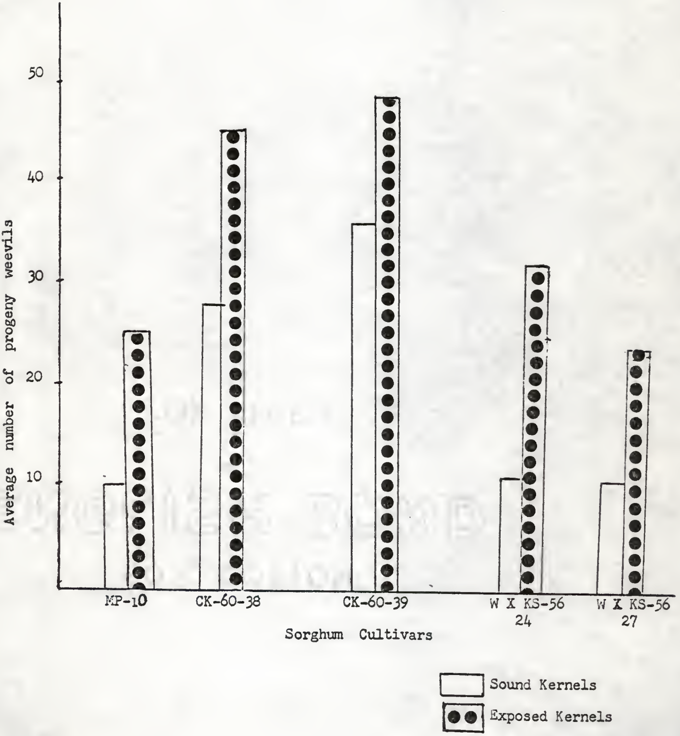
Table 5 (cont'd).

LSD's with 0.05 protection level
Significant range = 4.57

Significantly different groupings of means

Cultivar	Treatment	Means
CK-60-39	exposed kernels	47.00 a
CK-60-38	exposed kernels	45.00 a
CK-60-39	sound kernels	36.00 b
WIRU X KS-56-24	exposed kernels	31.67 b
CK-60-38	sound kernels	27.67 c
WIRU X KS-56-27	exposed kernels	23.67 d
MP-10 Shallu (Res. ck)	exposed kernels	21.00 e
WIRU X KS-56-27	sound kernels	11.33 f
WIRU X KS-56-24	sound kernels	10.67 f
MP-10 Shallu (Res. ck)	sound kernels	9.67 f

Fig. 3. Rice weevil development on 5 sorghum cultivars, sound and exposed kernels.



50
40
30
20
10
Average number of progeny weevils
MP-10
CK-60-38
CK-60-39
W X KS-56 24
W X KS-56 27
Sorghum Cultivars
Sound Kernels
Exposed Kernels

Discussion

In all cultivars, rice weevils laid more eggs in kernels that were previously exposed to weevil attack than in kernels that were not. The progeny weevil production, however, increased more in previously resistant cultivars than in the susceptible cultivars. Perhaps the previous weevil feeding on the resistant pericarp made it rougher, thus more suitable for oviposition during the second exposure. Weevils probably could better grasp the kernels with both tarsi and mandibles during oviposition.

Also, kernels that escaped oviposition during the initial exposure might have possessed factors on the pericarp which made the kernels not preferred by female weevils for oviposition, and that weevil feeding during both exposures might have neutralized these factors, thus rendering the kernel more suitable for oviposition. The weevils might have laid down pheromones (an external chemical messenger) at the first exposure which might have stimulated mating and oviposition during the second exposure of kernels to rice weevil.

Schoonhoven et al. (1972) found an increase in progeny production at the second exposure of corn kernels to weevil oviposition but they got no further increase in either progeny weevils during the third and subsequent exposure to weevils. The factors that were related to resistance might have been removed at the first exposure to feeding.

Previous exposure of the kernels to weevils might also have made it easier for the adult ovipositing weevils to feed on the kernels, hence have more energy for oviposition. Chapman (1975) recorded that insect fecundity is largely related to adult nutrition and House (1963) concluded that dietary deficiencies might result in a disturbance of yolk synthesis. Developmental periods of the progeny weevils and their live weights in the more resistant and more susceptible cultivars were not significantly different, either in previously exposed or unexposed kernels. The "progeny counts" method was best for indicating level of resistance or susceptibility of the sorghum cultivars to rice weevils.

This study confirmed the importance of undamaged pericarp in conferring resistance to weevil damage on sorghum kernels.

TEST VI. EVALUATION OF RICE WEEVIL RESISTANCE OF SELECTED SORGHUM CULTIVARS IN PELLET FORM

Introduction

Grinding and pelleting sorghum grain is a technique for detecting antibiosis type of resistance to the weevils (Schoonhoven, 1972). Pelleting destroys the physical nature of the intact pericarp which seems to be related to resistance. Schoonhoven (1972) and Bell (1971) used the pelleting technique to study nutritional requirements of maize weevils and Angoumois grain moths, respectively.

This study was to investigate possible antibiosis type of resistance to rice weevils in 7 selected sorghum cultivars. Larval mortality would indicate the presence of antibiosis.

Materials and Methods

Schoonhoven's (1972) pelleting technique was used for each cultivar:

1. Sorghum kernels were ground through a 40-mesh sieve in a Wiley laboratory mill.

2. 0.2 g agar was added to 15 ml of water.

3. The mixture was brought to boiling, cooled, and mixed with 10 g of sorghum flour.

4. Before solidification, the liquid was poured into a plastic box (4.8 x 4.8 x 1.8 cm).

5. After solidification the medium was cut into 25 squares of nearly equal size.

6. The pieces were dried at 50°C in an oven for 24 hours.

I made 3 replicates of pellets for each selected sorghum (MP-10 Shallu, CK-60-38, CK-60-39, CK-60-14, WIRU X KS-56-30, WIRU X KS-56-24, and WIRU X KS-56-27). Each replicate consisted of 25 pellets in a plastic screening cage (4.8 x 4.8 x 1.8 cm). All samples were equilibrated in the rearing room for 15 days.

Using the no-choice technique I placed 6 female and 4 male rice weevils in each replicate for a 5-day oviposition period.

To compare with the pelleted sorghums I likewise set up three replicates of undamaged kernels (100 kernels each) of each selected cultivar.

I counted progeny weevils daily as they emerged and recorded the live weight of each.

Results

The number of progeny weevils from sorghum pellets varied from 11.33 to 32.00 (Table 6). Except for WIRU X KS-56-30, pellets of all the resistant cultivars yielded as many or more rice weevils than whole kernels. The 2 susceptible sorghums (CK-60-39 and CK-60-38) yielded more weevils as whole kernels. WIRU X KS-56-24 yielded the largest number of progeny weevils after pelleting and WIRU X KS-56-30 the least. MP-10 Shallu, the most resistant as kernels, became more susceptible after pelleting than pelleted CK-60-39, which was the most susceptible cultivar as whole kernels. CK-60-39 was the most susceptible cultivar as whole kernels (41.67 progeny weevils) but yielded the fewest (17.33) weevils as pellets.

Table 6. Rice weevil progeny development in 7 sorghum cultivars as whole kernels or pellets (3 replicates of each; no-choice oviposition; 6 female and 4 male parent RW/rep; 5-day oviposition period).

Cultivar	Treatment	Avg. no. of progeny/rep.	Avg. days from oviposition-emergence	Avg. live weight (mg)
MP-10 Shallu	whole kernels	10.00	32.50	2.000
	pelleted whole kernels	25.00	39.40	1.600
CK-60-38	whole kernels	34.00	30.30	1.940
	pelleted whole kernels	21.00	36.45	1.920
CK-60-39	whole kernels	41.67	30.63	2.195
	pelleted whole kernels	17.33	42.40	2.000
WIRU X KS-56-30	whole kernels	18.33	34.43	1.960
	pelleted whole kernels	11.33	45.20	1.800
WIRU X KS-56-24	whole kernels	14.00	32.56	1.940
	pelleted whole kernels	32.00	38.32	1.900
WIRU X KS-56-27	whole kernels	12.00	32.53	1.920
	pelleted whole kernels	12.00	40.34	1.550
CK-60-14	whole kernels	12.67	31.70	1.900
	pelleted whole kernels	26.67	42.50	1.800

Analysis of Variance. Variate = Progeny weevil number

Due to	Sum of squares	D.F.	Mean square	F	$\hat{\text{Alpha}}$
Between cultivars	1592.62	6	265.44	53.65	0.000
Pelleting	4.67	1	4.67	0.05	0.339
Interaction	2237.00	6	372.83	75.643	0.000
Within cultivars	138.01	28	4.93		

Table 6 (cont'd).

Cultivar	Significantly different groupings of means Treatment	Means
CK-60-39	whole kernels	41.67 a
CK-60-38	whole kernels	34.00 b
WIRU X KS-56-24	pelleted kernels	32.00 b
CK-60-14	pelleted kernels	26.67 c
MP-10 Shallu	pelleted kernels	25.00 c
CK-60-38	pelleted kernels	21.00 d
CK-60-39	pelleted kernels	18.33 d
WIRU X KS-56-30	whole kernels	17.33 de
WIRU X KS-56-24	whole kernels	14.00 e
CK-60-14	whole kernels	12.67 f
WIRU X KS-56-27	whole kernels	12.00 fg
WIRU X KS-56-27	pelleted kernels	12.00 fg
WIRU X KS-56-30	pelleted kernels	11.33 fg
MP-10 Shallu	whole kernels	10.00 g

LSD = 3.71 with 0.05 protection level

No adult mortality was recorded in any replicates. Developmental periods of the rice weevils in all cultivars were longer in pellets than in whole kernels (Table 6). In pellets, developmental periods (oviposition to adult emergence) varied from 36.4 to 45.2 days; in whole kernels, 30.3 to 34.4. Developmental period was longest in pellets of WIRU X KS-56-30 and shortest in whole kernels of CK-60-38.

Average live weights of progeny weevils were less from pellets than from kernels.

Discussion

Most resistant sorghum cultivars in pellet form yielded more progeny weevils than susceptible cultivars, as whole kernels. This did not indicate antibiosis. The variation in numbers of progeny weevils from pellets might be due to the physical nature of each pellet. Previous studies show that susceptible cultivars contain more pericarp than resistant cultivars (White, 1975). The fibrous pericarp in pellets probably reduced the ability of the larvae to feed on essential nutrients for growth and development (K. O. Bell, 1971). Schoonhoven et al. (1972) found that adding 1 g or 2 g of pericarp to 3 g of flour of corn lines and pelleting them resulted in significantly lower progeny numbers, longer developmental periods, and reduced weights.

Pellets of susceptible cultivars crumbled more than those of resistant cultivars; this did not provide a favourable microhabitat for larvae to develop in pellets of susceptible cultivars.

Physical nature of the pellets and its effect on their moisture contents might have resulted in longer developmental periods for larvae and also their decreased live weights. Schoonhoven et al. (1972) found significant differences in developmental periods and in sizes of weevils from different lines of corn but did not detect antibiosis.

More than one progeny weevil emerged from some cultivar's pellets (MP-10 Shallu and WIRU X KS-56-24). No antibiosis was, however, detected.

TEST VII. PERICARP CHARACTERS OF 4 SORGHUM CULTIVARS IN RELATION TO OVIPOSITION RATES

Introduction

Previous studies suggest that rice weevils prefer to oay eggs on sorghum varieties with soft seeds. An average of 1.2 eggs/day are laid by a single weevil (Lathrop, 1914) but may lay as many as 9. He found a maximum of 63 eggs laid in 46 days by one rice weevil, at 27°C and 68% RH.

The rate of oviposition as well as the total number of eggs deposited varies with conditions. Doggett (1957, 1958) found that rice weevil damage to sorghum in storage was less as the corneous endosperm layer was thicker.

Russell (1962) recorded fewer eggs deposited by female rice weevils on sorghum varieties with relatively hard seeds.

White (1975) found a positive relationship between pericarp thickness and the number of progeny produced by maize weevils on sorghum cultivars.

This study investigated the non-preference mechanism of resistance exhibited by some sorghum cultivars and the role of the pericarp in resisting rice weevil oviposition.

Materials and Methods

I selected 2 resistant and 2 susceptible sorghum cultivars. One hundred seeds of each were used per test box, 6 female and 4 male rice weevils were placed in each of 18 replicate samples of each cultivar under no-choice conditions. Twenty-four hours later, and each 24 hours thereafter to 144 hours, the weevils were removed from 3 replicates of each cultivar. An attempt was made to count egg plugs on the kernels of each of those samples after acid fuchsin staining (Frankenfeld, 1948). All samples were held in 27°C, 67% RH, and 12-hour photoperiod for progeny emergence.

The scanning electron microscope (SEM) was used to observe the cross-sections of the selected sorghum cultivars.

Results and Discussion

Results from egg plug counts were not reliable because it was difficult to detect the stained egg plugs in sorghum kernels. The number of progeny rice weevils was therefore used to determine oviposition rates.

Oviposition rates varied between cultivars (Table 7). More eggs were deposited in susceptible cultivars (CK-60-38 and CK-60-39) per unit time.

Overall average oviposition for 6 female weevils in 24 hours was 3.14, 2.9, 6.62 and 9.95 for MP-10 Shallu, WIRU X KS-56-24, CK-60-38 and CK-60-39, respectively, as measured by progeny weevils.

There was no significant difference in the oviposition rate of the rice weevils within each cultivar sample for the period of 6 days. In CK-60-39, however, the weevils showed an apparent cessation of oviposition after a period of 72 hours, since total progeny number didn't increase, except for the 144-hour oviposition period.

This decrease might be due to the greater probability of oviposition in kernels already with eggs in them, and the resulting internecine activity.

The total number of progeny rice weevils produced within the same cultivar for a period of 6 days fitted a linear regression model, shown by the prediction equation below. Cumulative progeny weevils produced by each cultivar increased daily (Table 7). The analysis of variance for progeny weevils produced showed a significant difference in the total number of progeny weevils produced including all oviposition periods between the selected sorghum cultivars.

SEM photograph of the pericarp surface of each selected sorghum cultivar revealed the presence of "superficial wax" (Fig. 6). After attempted quick ether removal of the "superficial waxes" from kernels, progeny production was slightly higher, but non-significant (Table 8). Wax removal probably was not complete. SEM photographs showed little difference between washed pericarp surface (in ether) and unwashed kernels.

Other organic solvents should be tried to obtain better extraction of the "superficial waxes" from the sorghum kernels and hence to show their influence on resistance.

The differences in the response of female rice weevils to oviposit on the kernels of selected sorghum cultivars indicated that non-preference was a factor.

The SEM photograph showed variations between the pericarp-seed coat thickness of the sorghum cultivars. Susceptible cultivars had thicker pericarp-seed coat and more starch granules in the mesocarp while MP-10 Shallu had a thinner pericarp-seed coat and few or no starch granules in the mesocarp. In contrast to White's (1975) finding (a positive correlation, 0.68, between pericarp thickness and numbers of rice weevil progeny), the WIRU X KS-56-24, though a resistant cultivar, had a thick pericarp-seed coat with starch granules in the mesocarp. Resistance of WIRU X KS-56-24 and MP-10 Shallu might be influenced by non-preference during oviposition and perhaps the firmness of the pericarp of MP-10 Shallu was a resistance factor.

Table 7. Average number of progeny rice weevils, 3 replications of 6 females in each of 4 selected sorghum cultivars, after each of 6 different oviposition periods (100 kernels/rep., 6 female and 4 male parent RW/rep.; no-choice).

Period of oviposition (hr) (3 rep/time period)	Avg. no. progeny weevils produced by 6 females							
	MP-10 Shallu		WIRU X KS-56-24		CK-60-38		CK-60-39	
	Total	Avg/24 hrs	Total	Avg/24 hrs	Total	Avg/24 hrs	Total	Avg/24 hrs
24	3	3	2	2	5	5	11	11
48	5	2.5	6	3	13	6.5	24	12.0
72	9	3.0	8	2.67	15	5.0	41	13.67
96	14	3.5	11	2.75	29	7.25	40	10.0
120	16	3.2	14	2.8	31	6.2	40	8.0
144	19	3.17	20	3.3	46	7.67	53	8.83
Mean for 6 weevils/24 hrs		3.14		2.9		6.62		9.95

Analysis of Variance; variable = progeny counts

Source of variation	D.F.	Sum of squares	Mean squares	F ratio	$\hat{\text{Alpha}}$
Between cultivars	3	1534.04	511.35	31.70	0.0000
Time/cultivar	3	523.04	174.35	10.81	0.0002
Time	1	3067.51	3067.51	190.15	0.0000
Residual	19	306.51	16.13		
Total	26	6236.52			

Table 7 (cont'd).

Prediction Equations	
MP-10 Shallu	$Y_1 = 0.827 + 3.743X$
WIRU X KS-56-24	$Y_2 = 0.375 + 3.078X$
CK-60-38	$Y_3 = 2.18 + 7.357X$
CK-60-39	$Y_4 = 4.93 + 8.321$

Table 8. Rice weevil development on 2 sorghum cultivars after washing kernels with ethyl ether.

Cultivar	Treatment	Progeny weevils
MP-10 Shallu	none	12.7
	washed in ethyl ether	14.1
CK-60-38	none	39.6
	washed in ethyl ether	43.2

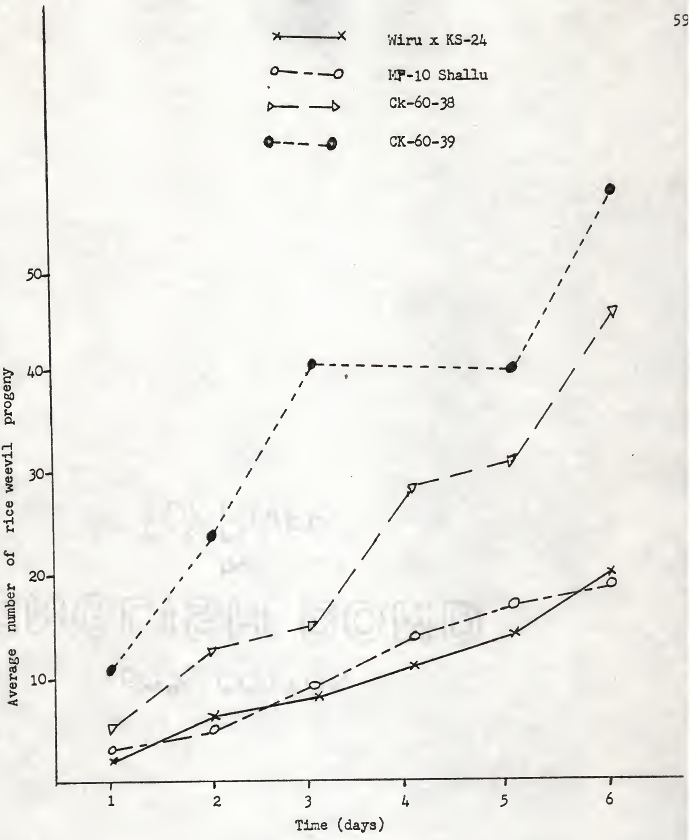

Wiru x KS-24
MF-10 Shallu
Ck-60-38
CK-60-39
Average number of rice weevil progeny
10
20
30
40
50
1
2
3
4
5
6
Time (days)

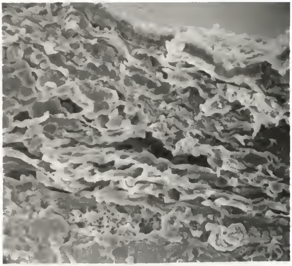
Fig. 5. Scanning electron micrograph with 1500X magnification.

(a)-(e) cross-sections through the pericarp seed coat of resistant and susceptible sorghum cultivars.

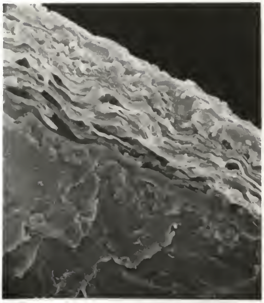
(b), (c) and (d) are resistant to rice weevil damage.

(e) is intermediate.

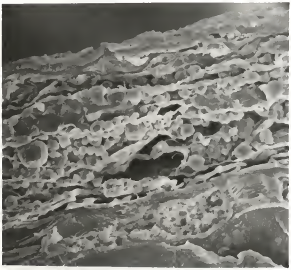
(a) is a susceptible cultivar.



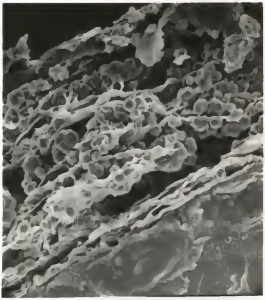
(a) CK-60-38



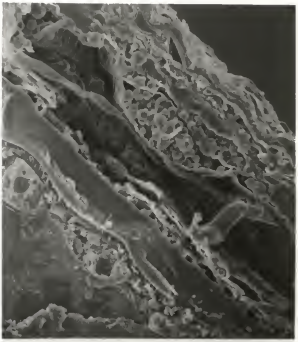
(b)MP-10 Shallu



(c) WIRUX KS56- 27



(d) WIRUX KS-56-24

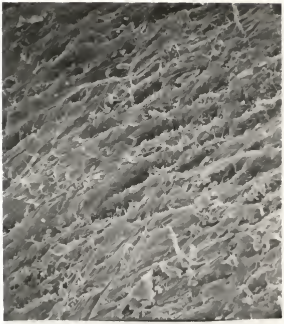


(e) WIRU X KS-56-30

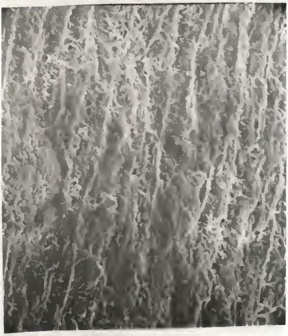
Fig. 6. Scanning electron micrograph with 1500X magnification.

(a)-(d) pericarp surfaces of resistant and susceptible sorghum cultivars.

(a) MP-10- Shallu



(b) CK-60-38



(c) WIRU X KS-56-24

(d) WIRU X KS-56-27

TEST VIII. RICE WEEVIL EGG HATCHABILITY AND LARVAL DEVELOPMENT IN KERNELS OF 5 SELECTED SORGHUM CULTIVARS

This study investigated the hatchability of weevil eggs and the number of larvae that developed to adult weevils from kernels of 5 selected sorghum cultivars.

Materials and Methods

I infested each of 2 replicate samples (100 kernels each) of the selected sorghum cultivars with 6 female and 4 male rice weevils. After a 5-day oviposition period the kernels were stained with acid fuchsin (Frankenfeld, 1948) to detect egg plugs. I used a binocular microscope to select randomly 10 kernels with stained egg plugs from each sample and placed the kernels in the rearing room ($27\pm1^{\circ}C$ and $67\pm3\%$ RH) for 20 days, after which I X-rayed the kernels and counted the larvae from the radiograph. The 10 kernels were later returned to the rearing room for emergence of progeny weevils.

Results and Conclusion

Almost all the 10 selected kernels with egg plugs in each sorghum sample produced rice weevil larvae except MP-10 Shallu that produced an average of 95%; this might be due to an error of selecting a kernel without an egg plug (Table 9).

This test showed that under each egg plug was an egg and that under the rearing room conditions ($27\pm1^{\circ}C$ and $67\pm3\%$ RH) all the eggs laid by the weevils hatched and were developing.

Table 9. Rice weevil egg hatchability and larval development in 5 selected sorghum cultivars (10 randomly-selected kernels with egg plugs/sample).

Cultivar	Avg. no. of eggs hatched/sample	Avg. no. of progeny weevil/sample	Percentage rice weevil egg hatchability
MP-10 Shallu	9.5	9.5	95
CK-60-38	10.0	10.0	100
CK-60-39	10.0	10.0	100
WIRU X KS-56-24	10.0	10.0	100
WIRU X KS-56-27	10.0	10.0	100

SUMMARY

This study investigated factors that might cause sorghum grains to resist rice weevils. The Kansas strain rice weevils used were cultured on sorghum in the rearing room at $27 \pm 1^{\circ}C$ and $67 \pm 3\%$ RH. Most sorghum cultivars were provided by the Kansas Branch Experiment Station at Fort Hays. Forty cultivars, including Combine Kafir (CK-60), WIRU X KS-56 and MP-10 Shallu, were tested for rice weevil resistance by the "free-choice" oviposition method; 8 sorghum cultivars then were selected to be tested for factors possibly related to resistance or susceptibility to rice weevil damage. Progeny production varied from 40 for the most susceptible cultivar (CK-60-39) to 5 for the most resistant cultivar (WIRU X KS-56-24). The WIRU X KS-56 crosses were more resistant than the Combine Kafir-60 selections.

Abrading the pericarp rendered resistant sorghum cultivars as susceptible as abraded susceptible cultivars, which indicated that the undamaged pericarp of resistant cultivars possessed a factor(s) of resistance which was eliminated by abrasion. The weevil developmental period was longer in damaged kernels than in undamaged kernels because not all resistance factor(s) was destroyed by damaging the pericarp.

A second exposure of selected sorghum cultivars to rice weevils broke down pericarp resistant factor(s). In all cultivars, rice weevils laid more eggs in kernels previously exposed to weevil attack than in kernels not previously exposed. Progeny weevil production increased more in previously resistant cultivars than in susceptible cultivars.

Weevils were reared in pellets made of 98% ground sorghum and 2% agar to investigate possible antibiosis type of resistance to rice weevil. After being pelleted, most resistant sorghum cultivars produced more progeny weevils than susceptible cultivars. No mortality of ovipositing adults was recorded; average live weights of progeny weevils were, however, less than from whole kernels. Larval developmental period was also longer in pellets. No antibiosis was detected.

Scanning electron microscope (SEM) photographs of the pericarp surface of each selected sorghum cultivar revealed superficial waxes. Attempted removal of the waxes with ethyl ether led to slightly higher (non-significant) progeny production. The ethyl ether probably did not remove all wax; other solvents and methods should be used in further tests.

Pericarp characteristics in relation to resistance were investigated using SEM photographs. The photographs revealed that pericarp-seed coat thickness varied among sorghum cultivars. Susceptible cultivars had thicker pericarp-seed coat and more starch granules in the mesocarp. Oviposition rates also varied among cultivars.

More eggs were deposited in susceptible cultivars per unit of time. Overall average oviposition for 6 female weevils varied from 3.14 eggs/24 hr on 100-kernel samples of resistant cultivars to 9.95 eggs/24 hr on samples of susceptible cultivars. Rice weevils preferred to deposit eggs on susceptible cultivars with thicker pericarp-seed coat than on cultivars with thin and harder pericarp-seed coat.

Surface damage and breaking sorghum kernels during harvesting and handling could destroy resistance to rice weevil attack.

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LITERATURE CITED

Ali, M. H. (1950). Some sorghum insects and their damage to seeds in the field and storage. Ph.D. Dissertation, Kansas State College, Manhattan.

Artschwager, E., and R. C. McGuire (1949). Cytology of reproduction in Sorghum vulgare. J. Agric. Res. 78:659-673.

Baker, J. E. and J. A. Mabie. 1973. Growth responses of larvae of the rice weevil on a meridic diet. Ann. of Entomol. Soc. Amer. 66(4):723-726.

Baker, J. E. Differential sterol utilization by larvae of Sitophilus oryzae and Sitophilus granarius. Ann. Entomol. Soc. Amer. 67(4): 591-594.

Breese, M. H. (1960). The infestibility of stored paddy by Sitophilus sasakii (Tak.) and Rhyzopertha dominica (F.). Bull. Entomol. Res. 51(3):599-630.

Chapman, R. F. (1975). The Insects. Structure and Function. American Elsevier Publishing Company, Inc., New York. 819 pp.

Cher, Choa-Hsi. 1938. The development of vascular tissues and the initiation of the inflorescence in Holcus sorghum L. Iowa State Coll. J. Sci. 12:217-225.

Chippendale, G. M. 1972. Dietary carbohydrates: Role in survival of the adult rice weevil, Sitophilus oryzae L. J. Insect Physiol. 18:949-957.

CIMMYT. Annual Report, 1970-71. International Maize and Wheat Improvement Centre. Mexico 6, D.F., Mexico. pp. 87-91.

Cotton, R. T. 1963. Pests of stored grain products (rev. ed.). Burgess Publishing Co., Minneapolis, Minn. 318 p.

Cowgill, H. B. 1926. Some panicle characteristics of sorgo. U. S. Dept. Agr. Bull. 1386.

Dalel, S. K. and D. S. Gupta. 1974. Relative resistance of some varieties of wheat to Sitophilus oryzae and Rhizopertha dominica (F.) at different temperatures. Bull. of Grain Technology 12(2):117-123.

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

Doggett, H. 1957. The breeding of sorghum in East Africa I. Weevil resistance in sorghum grains. Empire J. Exptl. Agric. 26(10):37-46.

Doggett, H. 1958. The breeding of sorghum in East Africa II. The breeding of weevil resistant varieties. Empire J. Exptl. Agric. 26(10):37-46.

Eastham, L. E. S. and F. Segrove. 1946. The influence of temperature and humidity on instar length in Calandra granarius Linn. J. Malaysia Inst. 5:79-93.

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

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

Food and Agricultural Organization of the United Nations. 1975. Month. Bull. Agric. Econ. Stat. 9:24. Rome. F. A. O.

Frankenfeld, J. C. 1948. Staining methods for detecting weevil infestation in grain. U. S. Dept. Agric. Bur. Entomol. and Plant Quar. E. T. Series 256. p. 4.

Giles, P. H. 1964. The insect infestation of sorghum stored in granaries in Northern Nigeria. Bull. Entomol. Res. 55:573-588.

Giles, P. H. 1965. Control of insects infesting stored sorghum in Northern Nigeria. J. Stored Prod. Res. 1:145-158.

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

House, H. L. 1963. Nutritional diseases in Steinhouse, E. A. (Ed.) Insect Physiology. Vol. 1. Academic Press, New York.

Hubbard, J. E., H. H. Hall, and F. R. Earle. 1950. Composition of the component parts of the sorghum kernel. Cereal Chem. 27:415-420.

Khalifa, A. 1962. The relative susceptibility of some varieties of sorghum to Trogoderma attack. Empire J. Exp. Agr. 30:132-136.

Lathrop, H. F. 1914. Egg-laying of the rice weevil Calandra oryzae Linn. The Ohio Nat. 14(7):321-328.

Maneechoti, P. 1974. Studies of resistance of 92 sorghum and 39 maize cultivars to 4 species of stored product insects. M. S. Thesis, Kansas State University, Manhattan. 107 p.

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

Miller, F. R. 1968. Some diversity in the world sorghum collection. Proc. 23rd Ann. Corn and Sorghum Res. Conf. 120-128.

Munro, J. W. 1966. Pests of stored products. Hutchinson and Co. Ltd. London. 234 pp.

Musgrave, A. J. and Grinyer. 1968. Membrane associated with the disintegration of mycetomal microorganisms in Sitophilus zeamais (Mots.). J. Cell Sci. 3:65-70.

Musgrave, A. J. 1964. Insect Mycetomes. Can. Entomol. 96:377-389.

Nwanze, K. F., E. Horber and C. W. Pitts. 1975. Evidence of ovipositional preference of Callosobruchus maculatus for cowpea varieties. Environ. Entomol. 4:409-412.

Nwanze, K. F. and E. Horber. 1975. How seed size affects the occurrence of "active" and "miniature" forms of Callosobruchus maculatus in laboratory populations. Environ. Entomol. 4:729-732.

Paulson, I. W. 1969. Embryogeny and caryopsis development of Sorghum bicolor (L.) Moench. Crop Sci. 9:97-102.

Powell, J. D. and E. H. Floyd. Effect of grain moisture upon development of the rice weevil in green corn. J. Econ. Entomol. 53(3):456-458.

Pruthi, H. H. and M. Singh. 1950. Pests of stored grain and their control. India J. Agric. Sci. 18(4):1-88.

Reddy, D. B. 1950b. Influence of sound kernels compared with halved kernels of wheat upon oviposition of the rice weevil. J. Econ. Entomol. 43(3):390-391.

Rhine, J. J. and R. Staples. Effect of high amylose field corn on larval development growth and survival of five species of stored grain insects. J. Econ. Entomol. 61:280-282.

Rogers, R. R. and R. B. Mills. 1974. Evaluation of world sorghum collection for resistance to the maize weevil, Sitophilus zeamais Motsch. (Coleoptera: Curculionidae). J. Kansas Entomol. Soc. 47:36-41.

Rossetto, C. H. 1966. Resistance of varieties of rough rice (paddy) to the Sitophilus zeamais Mot. (Coleoptera-Curculionidae). M. S. Thesis. Kansas State University, Manhattan. 120 p.

Rout, G. 1973. Studies of resistance of sorghum to Angoumois grain moths, Sitotroga cerealella (Olivier) and red flour beetles, Tribolium castaneum (Herbst). Ph.D. Dissertation. Kansas State University, Manhattan. 94 p.

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

Russell, M. P. 1966. Effects of four sorghum varieties on the longevity of the lesser rice weevil, Sitophilus oryzae (L.). J. Stored Prod. Res. 2:75-79.

Sanders, E. H. 1955. Developmental morphology of the kernel of grain sorghum. Cereal Chem. 32:12-25.

Schoonhoven, A. v., E. Horber, C. E. Wassom and R. B. Mills. 1975. Selection for resistance to the maize weevil in kernels of maize. Euphytica 24:639-644.

Schoonhoven, A. v., E. Horber and R. B. Mills. 1976. Conditions modifying expression of resistance of maize kernels to the maize weevil. Environ. Entomol. 5:163-168.

Schoonhoven, A. v. 1972. Aspects of resistance in corn selection to the maize weevil, Sitophilus zeamais Motschulsky (Coleoptera, Curculionidae). Ph.D. Dissertation. Kansas State University, Manhattan. 257 p.

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

Stevens, R. A. and R. B. Mills. 1973. Comparisons of techniques for screening sorghum grain varieties for resistance to rice weevil. J. Econ. Entomol. 66:1222-1223.

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

Ungsunantwiwat, A. 1976. Effects of culture media on the biology and behaviour of four populations of grain weevils. M. S. Thesis. Kansas State University, Manhattan.

VanDerSchaaf, P., D. A. Wilbur and R. H. Painter. 1969. Resistance of corn to laboratory infestation of the larger rice weevil, Sitophilus zeamais. J. Econ. Entomol. 62:352-355.

Venkatarao, S., R. W. Nuggehalli, M. Swaminothan, S. V. Pingale, and V. Subrahmanyan. 1956. Effect of insect infestation on stored grain III. Studies of kafir corn (<u>Sorghum vulgare</u>). J. Sci. Food Agric. 9:837-839.

Wall, J. S. and W. M. Ross. 1970. Sorghum production and utilization The AVI Publishing Company, Inc.

Watson, S. A., E. H. Sanders, R. D. Wakely and C. B. Williams. 1955. Peripheral cells of the endosperm of grain sorghum and corn and their influence on starch purification. Cereal Chem. 32:165-182.

White, S. C. 1975. Laboratory studies of levels and causes of insect resistance in varieties of stored sorghum. M. S. Thesis. Kansas State University, Manhattan. 70 p.

FACTORS RELATED TO RICE WEEVIL RESISTANCE IN SORGHUM CULTIVARS

by

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This study investigated factors that might cause sorghum grains to resist rice weevils. The Kansas strain rice weevils used were cultured on sorghum in a rearing room with $27\pm1^{\circ}C$ and $67\pm3\%$ RH. Most sorghum cultivars were provided by the Kansas Branch Experiment Station at Fort Hays. Forty cultivars, including Combine Kafir (CK-60), WIRU X KS-56 and MP-10 Shallu, were tested for rice weevil resistance using the "free-choice" oviposition method; 8 sorghum cultivars then were selected and tested for factors possibly related to resistance or susceptibility to rice weevil damage. Progeny production varied from 40 for the most susceptible cultivar (CK-60-39) to 5 for the most resistant cultivar (WIRU X KS-56-24). The WIRU X KS-56 crosses were more resistant than the Combine Kafir-60 selections.

Mechanically abrading the pericarp of resistant sorghum cultivars made them as susceptible as abraded susceptible cultivars, which indicated that the undamaged pericarp of resistant cultivars possessed a factor(s) of resistance which was eliminated by abrasion. The weevil developmental period was longer in damaged kernels than in undamaged kernels; cause was undetermined.

A second exposure of the kernels of selected sorghum cultivars to rice weevils broke down pericarp resistant factor(s). In all cultivars, rice weevils laid more eggs in kernels previously exposed to weevil attack than in kernels not previously exposed. Progeny weevil production increased more in previously resistant cultivars than in susceptible cultivars.

To investigate possible antibiosis type of resistance to rice weevils, they were reared in pellets made of 98% ground sorghum and 2% agar. After being pelleted, most resistant sorghum cultivars produced more progeny weevils than susceptible cultivars. No adult mortality was recorded; average live weights of progeny weevils were, however, less than from whole kernels. Larval developmental period was also longer in pellets. No antibiosis was detected.

Scanning electron microscope (SEM) photographs of the pericarp surface of each selected sorghum cultivar revealed superficial waxes. Attempted removal of the waxes with ethyl ether led to slightly higher (non-significant) progeny production. The ethyl ether probably did not remove all wax.

The role of pericarp in resisting rice weevil oviposition was investigated using SEM photographs. The photographs showed that pericarp-seed coat thickness varied among sorghum cultivars. Susceptible cultivars had thicker pericarp-seed coats and more starch granules in the mesocarp. Oviposition rates also varied among cultivars. More eggs were deposited in susceptible cultivars per unit time. Average oviposition rate for 6 female weevils varied from 3.14 eggs/24 hr on 100-kernel samples of resistant cultivars to 9.95 eggs/24 hr on samples of susceptible cultivars. Rice weevils preferred to deposit eggs on susceptible cultivars with thicker pericarp-seed coats than on cultivars with thin and harder pericarp-seed coats.

Damage to sorghum kernels during harvesting and handling no doubt makes them more susceptible to rice weevil attack.