EFFECTS OF CULTURE MEDIA ON THE BIOLOGY AND BEHAVIOUR OF FOUR POPULATIONS OF GRAIN WEEVILS (CURCULIONIDAE, SITOPHILUS)

by

AMPAI UNGSUNANTWIWAT

B. S., Kasetsart University
Bangkok, Thailand, 1970

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Entomology

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1976

Approved by:

Robert B. Mills

Major Professor

TABLE OF CONTENTS

INTRODUCTION

Cereal grains and their products are the main foods for man and livestock all over the world. Increasing world populations, and increased food production resulting from improved agricultural techniques, require safe storage for grains and their products. One of the major problems in stored grains results from stored-product insects.

Among the primary pests of stored grains are the true grain weevils (Sitophilus spp.) which are internal feeders and usually require whole cereal grains for their oviposition and development. The other common internal grain feeders are the Angoumois grain moth, Sitotroga cerealella (Olivier), and the lesser grain borer, Rhyzopertha dominica Fab. The true grain weevils are small in size and larvae develop internally, which makes them difficult to detect in the early stages of an infestation of stored grain. They cause both direct and indirect damage; directly, they cause loss of weight, loss of nutrition and loss of viability of grain; indirectly, they contaminate grain by their presence and their feces, and provide damaged grains for other insect pests. Severe infestations of grain may cause "hot spots" which cause moisture migration that can result in severe losses due to molds and other microorganisms.

There are three species of true grain weevils which have been separated morphologically. They are the rice weevil, Sitophilus oryzae (Linn.); the granary weevil, Sitophilus granarius (Linn.) and the maize weevil, Sitophilus zeamais (Mots.). They all have the same host range, but differ in their biology and behaviour. There is sometimes a problem in identification of these three species reared in different foods and in geographic locations.

Besides *S. oryzae* and *S. granarius*, two different geographical populations of *S. zeamais* were studied, a Mexican population and an Arkansas population. All were studied using three different kinds of media: wheat, sorghum and corn.

This research included studies of variations in biology and behaviour within the individual population and among the four populations as they were affected by physical disturbance, and by both parent and progeny rearing media. Variations in sizes within the same population and among the four populations as related to parent size, and both parent and progeny rearing media, were studied. Weight loss was determined of individual kernels of wheat, sorghum or corn caused by the development of single insects from each population, and weevil weights were recorded. Sex ratios were determined in the four populations from different media. The effects of quantities of wheat, sorghum or corn on the reproduction of the rice weevil were determined. The research began on January 3, 1975 and was carried on over twelve months.

REVIEW OF LITERATURE

The *Sitophilus* complex has been morphologically separated into three species, *S. oryzae* (L.), *S. zeamais* (Mots.) and *S. granarius* (L.). Characters for distinguishing them have been studied by several workers. Hunkapiller and O'Donnell (1967) distinguished the larvae of the three species, *S. oryzae* (Kansas strain), *S. granarius* (Kansas laboratory strain) and S. zeamais (Arkansas strain). They found that the frons permitted the means for species separation. McLaurin and Downe (1966) compared the three species by precipitin tests on the adult weevil antigens and found that they were distinguishable serologically. Floyd and Newsom (1959) found reproductive separation between the "small strain" rice weevil (S. oryzae) and the "large strain" (S. zeamais) by the right sternum of the female and in the shape of a sclerite on the dorsal surface of the aedeagus of the male.

Recently, many workers have considered the variation in biology and behaviour of the three species in different kinds of hosts. There has been interest in different populations. Soderstrom and Wilbur (1966) studied the variations in three geographical populations of the rice weevil complex, "Louisiana and Kansas oryzae" and "Arkansas zeamais" in different varieties of wheat, sorghum and corn. They found that when given a choice, Louisiana and Kansas oryzae oviposited approximately 70% of their eggs on Martin sorghum, 20% on Ponca wheat and 10% on KS 1639 corn. The Arkansas population deposited 58% on KS 1639 corn, 29% on Martin sorghum and 13% on Ponca wheat. They also found that the total reproduction of both oryzae populations was greater in wheat and sorghum, and less in corn, compared to Arkansas zeamais. Similar studies had been done by Floyd and Newsom (1959) on the "small rice weevil" which they called Sitophilus sasakii (Tak.) and the "large rice weevil" which they called Sitophilus oryza (L.). They stated that reproduction of both species was least in corn, next in rough rice and greatest in grain sorghum. S. oryza reproduction was greater in unpolished rice than in wheat, but S. sasakii reproduction was greater in wheat.

The variable developmental times among the populations of grain weevils have been studied. Soderstrom and Wilbur (1966) reported the developmental times from the beginning of oviposition until 70% of the progeny had emerged; Kansas oryzae developed fastest on Ponca wheat (38 days, mean), intermediate on sorghum (48 days), and slowest on KS 1639 corn (55 days), while the Arkansas zeamais required shorter developmental time when reared on all grains, Martin sorghum (37.3 days), Ponca wheat (40 days) and KS 1639 corn (44 days). Average developmental period in all grains for Kansas oryzae was 41.7 days and for Arkansas zeamais, 39.1 days. Sharifi and Mills (1971) reported that the average length of developmental period of Arkansas zeamais in wheat from the start of the three days oviposition to the adult emergence was 36.3 days. Boles (1975) reviewed previous studies by workers using the Arkansas zeamais. S. granarius (L.) developmental time in wheat averaged 67.6 days at 20°C, 36.6 days at 25°C, and 32.6 days at 30°C (Surtees, 1965). He also found that size of kernel within the same kind of grain did not affect the developmental period at any temperature, but when insects were bred at 25°C and 70% RH on broken grain that had passed through a sieve with 10 meshes/inch, the developmental period increased in 54.5 days.

Several workers have studied the influences of rearing medium on weight and length of the insects. According to Maceljski and Korunic (1971), assembling the previous studies of S. oryzae and S. zeamais, they found that when both were reared in wheat the average weight of S. zeamais was 2.09 mg (range, 1.1-2.9 mg) and S. oryzae was 1.01 mg (range 0.6-1.5 mg). They also stated that body length depended upon type of food, e.g., under given conditions S. oryzae may be larger than S. zeamais. If both species developed on the same food (wheat or corn), S. zeamais will be significantly larger. Comparison among three geographical populations of rice weevils in different varieties of wheat, sorghum and corn were done by Soderstrom and Wilbur (1965); they reported that Louisiana oryzae was the lightest, averaging 1.2 mg (range, 1.0 mg to 1.4 mg); Kansas oryzae was intermediate, averaging 1.6 mg (range, 1.3 mg to 1.9 mg) and the Arkansas zeamais was heaviest, 2.3 mg (range, 2.9 mg to 3.0 mg). Length of the right elytron was also determined. Louisiana oryzae had the shortest elytra, ranging from 1.12 mm in wheat to 1.61 mm in corn; Kansas oryzae was intermediate, ranging from 1.22 mm on wheat and corn to 1.61 mm on sorghum, and the Arkansas zeamais had the largest, ranging from 1.57 mm on wheat to 1.91 mm on corn. Richards (1943) stated that rice weevils vary greatly in size, and it is a natural assumption that the kind of grain in which they are breeding is the main cause of variation. Food influence on size of the "large strain" that had been breeding on corn from different parts of Australia was studied by Birch (1956) and he recorded 3.2 mm and 3.3 mm as mean combined lengths of elytra and pronota. After rearing them in wheat for several generations, he found that the mean length was 2.9 mm, significantly different from that of the parents reared in corn. Similar measurements of a "small strain" which he collected from corn in Sydney revealed 2.7 mm in mean length of elytron and pronotum. After rearing them in wheat for several generations, he found that the "small strain" was smaller than the large strain also reared in wheat. Kiritani (1965) discussed that there is no reason to expect that S. zeamais will always be larger than S. oryzae when both are discovered in the same area. He also concluded that *S. oryzae* is differentiating into a larger and smaller-sized strain, the process representing adaptation to life in stored products, and that the small strain found in Japan represents an advanced stage in this adaptation.

Lavadinho (1975) found variations in body weight of adult *S. granarius* (L.) in wheat from normal cultures and crowded cultures; in crowded cultures parents produced significantly lighter progeny. He also added that weights of individual insects were approximately normally distributed, and that there was no significant difference between male and female adult mean weights. Surtees (1965) found that heavier adults of *S. granarius* emerged from heavier grains. The mean weights of emerging adults bred on two weight classes of wheat at 70% RH and 3 different temperatures were:

Temp. (°C)	Single kernel weights (mg)	
	30-35	50-55
	Insect weights (mg)	
20	2.59	3.05
25	2.51	2.86
30	1.99	2.41

He also found that the adults bred on broken grain at 25°C averaged 1.1 mg and took 50% longer to develop. Morrison (1965) studied the effect of particle size of sorghum grain on development of *S. zeamais* and reported that the largest number of adults emerged from whole sorghum kernels, and the least number from the coarsely-ground sorghum grain, but that it was possible for a population of S. zeamais to maintain a low level of infestation in coarsely and finely-fround particles of farinaceous substances.

Effect of physical disturbance on the reproduction of grain weevils has been studied by different means but also a few cases have studied the effect of mechanical disturbances. Joffe and Clarke (1963) reported that not only adults but also the pre-emergence stage of S. oryzae in corn could be readily killed by mechanical disturbance. The percentage mortality depended upon the frequency, timing and type of disturbance. Bailey (1969) also stated that physical disturbance of wheat in which immature stages of S. granarius (L.) were living might prevent many or all of the insects developing successfully. Disturbance was particularly effective when carried out regularly, such as daily or twice weekly and with very small forces; the impact due to the wheat falling only 23 cm had an effect. All immature stages of the insect were susceptible to regular disturbance but the pre-pupae and pupae were most susceptible. In some cases, disturbances of grain samples might maintain a better environment for development of weevils. This was studied by Morrison (1964); he reported that the undisturbed S. zeamais (Mots.) population perished in 8 weeks, while a population disturbed weekly maintained itself for 17 consecutive weeks. This brief existence of the undisturbed population was attributed to the adverse environment created by the weevils, which was unfavorable for their development but was apparently favorable for the development of fungi.

Weight loss of stored grain caused by insects depends largely upon the individual species. Hurlock (1965) determined that mean weight loss of wheat kernels caused by each *S. granarius* development from egg to adult was 28.7 mg and the mean weight of each adult produced was 2.7 mg. He found no significant differences among the amounts of damage caused at 25°C, 27.8°C, and 31.1°C at 70% RH. Singh et al. (1972) determined the differences in loss of weights of different varieties of wheat caused by *S. oryzae* at 30°C and 75% RH. The average actual loss of weight per "grub" ranged from 9.75 mg to 13.5 mg, and the mean weight of each adult produced ranged from 2.1 mg to 2.4 mg. Golebiowska (1969) reported that one *S. oryzae* larva consumed 10 mg of a wheat kernel and produced 0.69 mg of grain dust while the individual weight of the weevil was 1.37 ± .01 mg. The same worker found that one *S. granarius* larva ate 30 mg of a kernel and caused 5.7 mg of grain dust while the mean weight of adults was 2.59 ± .01 mg. The same worker found that one *S. granarius* larva ate 30 mg of a kernel and caused 5.7 mg of grain dust while the mean weight of adults was 2.59 ± .01 mg. Soderstrom and Wilbur (1966) in studies of Arkansas *zeamais* and two geographical populations of *S. oryzae*, found that *S. zeamais* ejected significantly greater amounts of frass from wheat kernels than the *S. oryzae*. White (1953) found that one *S. oryzae* larva consumed 3.76% of the average weight of the whole kernel of wheat and the actual weight loss per kernel was 5 times that of each emerged adult (average 1.22 mg).

There are variations in total reproduction by the same population when reared in the same grain or different kinds of grain. Howe and Hole (1967) studied the routine culture of *S. granarius*; they stated that the chief causes of variability in yield appeared to be the age and sex ratio of the parents. They also found that the number of eggs per weevil was increased if fewer weevils were placed on wheat. In most experiments, workers presumed that the sex ratio of adult weevils is unity (1:1) and according to the study of Howe (1952), the sex ratio of the adult rice weevils did not differ significantly from unity under any condition. Coombs (1972) described some factors that might affect the interpretation of experiments assessing the susceptibility of stored cereal grains to attack by Sitophilus. His suggestion was to take into account the size of individual kernel, the maximum number of the adults which could succeed in developing together within a single grain, and the cannibalistic behaviour of Sitophilus. He also suggested, for any experiment, that a large amount of grains should be available to reduce cannibalism.

GENERAL MATERIALS AND METHODS

Stock Insect Cultures

The four populations of grain weevils had been maintained in hard red winter wheat in Kansas State University's stored-product insect laboratory for several years.

1. The Mexican strain of maize weevil (MMW), Sitophilus zeamais (Mots.), was originally from the State of Veracruz, Mexico, and had been maintained in the KSU stored-product insect laboratory since September, 1964.

2. The Arkansas strain of maize weevil (AMW) was originally collected from farm-stored corn near Stuttgart, Arkansas, in 1955, and was introduced to the KSU stored-product insect laboratory in 1957.

3. The Kansas strain of rice weevil (RW), *S. oryzae* (L.), was obtained from the United States Department of Agriculture Stored-Product Insect Laboratory, Manhattan, Kansas and weevils of the same species from fields and elevators in Kansas had been mixed with this laboratory strain. However, none had been introduced within the last 10 years.

4. The strain of granary weevil (GW) was originally obtained from Kansas farm-stored wheat and had been maintained in the laboratory without addition of new stock for at least 10 years. The culture was started by mixing grain samples from different parts of Kansas.

Culture Media

The grains used were hard red winter wheat (Cloud variety), dark-brown grain sorghum (unknown variety) and yellow and white dent corn (mixed varieties). All were stored in a coldroom at 4.4°C until used.

Rearing Room Facilities

All stock cultures, experimental cultures, and all experiments were conducted in a rearing room with controlled temperature and relative humidity (27 ± 1°C, 68 ± 3% RH), and a 12:12 photoperiod.

Culture Media Preparation

All culture grain used was cleaned of dust and light contaminants using a Bates laboratory aspirator. Then other dockage was removed by using a hand sieve, U. S. standard testing sieve of 9 meshes/inch for wheat and sorghum grains, and 8 meshes/inch for corn. The grain was placed in tight gallon jars and transferred to a freezer of -16°C for

3 days in order to kill any possible insect and mite infestation, then returned to the coldroom until needed. Before use the grain was removed from the coldroom and the temperature allowed to equilibrate with the room temperature, and moisture was determined by using a laboratory Motomco moisture meter, Model 919. Usually, moisture equilibration was required, done by placing the grain in the rearing room at 67 $\pm$ 3% RH and 27 $\pm$ 1^{o}C which produced an equilibration moisture content of approximately 13.5%. The grain was placed in either quart or pint jars with fine screen lids with kelthane-treated filter paper, or in a small plastic box (48 x 48 x 18 mm) with fine screen lids, depending upon the particular experiment. Then the grains were allowed to equilibrate in the rearing room to 13.5% moisture content, for 2 to 4 weeks, depending upon the amount of grain in the samples.

Stock Culture Production

Parent stock from wheat for use in experiments was taken from the routine cultures in wheat in the laboratory. To prepare parent stock cultures in sorghum and corn, groups of 350-400 7-to-21-day-old adults of each strain (from wheat) were introduced separately into approximately 400 g of sorghum or corn in each wide mouth mason jar with 60-mesh screen lid and kelthane-treated filter paper above the screen for protecting against mites and other insects. After 7 days oviposition, all adults were removed and destroyed. To maintain a ready supply of stock insects in the three grains, two jars of parent stock cultures for each strain in each grain were set up weekly. For particular experiments that required more parent weevils, more jars of parent stock cultures were prepared.

PRODUCTION OF PROGENY

Materials and Methods

The parent weevils, S. zeamais (Mots.) (Mexican population), S. zeamais (Mots.) (Arkansas population), S. oryzae (L.) and S. granarius (L.) (both Kansas populations) were obtained from the stock insect cultures. All cultures had been continuously reared in wheat for several years; for this test, however, parent weevils used were also reared in corn and sorghum (one generation). The rearing media were wheat, sorghum and corn, obtained from the cleaned culture stock media. For each strain of parent weevils reared in each of the 3 grains, 6 250-g samples of each grain were placed in wide-mouth pint jars having 60-mesh screen lids. The moisture contents of the grains were 13-14% as determined by using a Motomco Moisture Meter, Model 919. All samples were allowed to equilibrate in the rearing room at 68 $\pm$ 3% RH and 27 $\pm$ 1^{o}C for 2 weeks. For each population 50 unsexed 7-to-14-day-old parent weevils reared in wheat, sorghum or corn were placed in each of 6 jars for 6 days oviposition. Parent weevils were removed and preserved in 70% isopropyl alcohol for later measurements. All samples were held in the rearing room. Twenty-four days after the beginning of oviposition, 3 of the 6 samples were observed daily for the first emergence of adult progeny, and 3 were not disturbed until the end of the experiment. The adult progeny were removed from the "handled" samples every 48 hr by using a hand sieve (U. S. Standard Sieve with 9 meshes/inch). This consisted of shaking the sample in the sieve approximately 55 times in 15 seconds. The progeny from all samples were preserved in 70% isopropyl alcohol for subsequent measurements. Sieving of "handled" samples ceased after 6 days without adult emergence. In cases of continued emergence of a few adults, sieving ceased just prior to expected emergence of any possible second generation progeny. From the 3 undisturbed samples, the total numbers of adult progeny were removed and counted on the same day of the last sieving of the 3 handled samples in the same treatment.

Results and Discussion

Effects of Handling. For the Arkansas maize weevil (AMW) and the granary weevil (GW) the average numbers of progeny produced by each in the 9 handled samples (3 for each grain), was significantly less (0.05 level) than that produced in the 9 unhandled samples (Table 1). Progeny production in the handled samples of the Mexican maize weevil (MMW) and the rice weevil (RW) was also lower than in the unhandled samples, but not significantly.

Table 1. Average numbers of progeny produced in handled or unhandled samples for 4 weevil populations. Each mean is for 9 samples (3 reps. for each of 3 grains).

	MMW	AMW	RW	GW
Handled	489.7	483.4	529.1	178.7
	n.s.	*	n.s.	*
Unhandled	541.8	576.7	571.3	201.9

n.s. = nonsignificant.
* = significant at the 5% level.

Effects of Parent and Progeny Rearing Media on Each Population. The average numbers of progeny of each insect population in each of the 3 grains when parents were reared in each grain are shown in Table 2.

Mexican Maize Weevil (MMW). Over-all average numbers of progeny produced by parents reared in wheat, corn and sorghum were 706.3, 473.8, and 367.1/sample, respectively, all significantly different. The over-all mean numbers of progeny produced in each grain by parents reared in all grains were 708.4 in sorghum, 585.4 in wheat and 253.3 in corn; all means differed significantly.

Shown in Table 2 are the results of analysis of variance of the mean numbers of progeny produced in wheat, sorghum or corn by parents reared in each medium. Parents from wheat produced more progeny in sorghum (890.7), which was significantly different from those produced in corn (357.3) but not from those produced in wheat (870.8). Mean numbers of progeny produced by parents from sorghum in sorghum (547.8), wheat (395.3), and corn (158.0) were significantly different. Parents from corn produced significantly different mean numbers of progeny in sorghum (686.8), wheat (490.2), and corn (244.5). The mean numbers of progeny produced in each of the 3 grains were greater from parents reared in wheat, intermediate in corn and least in sorghum. The means in wheat were 870.8, 490.2, and 395.3; in sorghum 890.7, 686.8, and 547.8; and in corn 357.3, 244.5, and 158.0. (The results are also illustrated in Plate I, Fig. 1.)

Arkansas Maize Weevil (AMW). The over-all means of the numbers of progeny produced in all 3 grains by parents reared in wheat, sorghum or corn were 632.2, 502.9 and 455.0/sample, respectively; parents reared

Table 2. Numbers of progeny produced by 50 parent weevils in wheat, sorghum or corn when parents were reared in each of the 3 grains. Six 250-g samples per test.

Parent rearing medium	Progeny rearing medium: Wheat Mean	Wheat Range	Sorghum Mean	Sorghum Range	Corn Mean	Corn Range	Over-all mean
			S. zeamais (MMW)				
Wheat	870.8 a	749-1069	890.7 a	647-1007	357.3 de	320-429	706.3
Sorghum	395.3 d	304-532	547.8 c	406-735	158.0 f	66-209	367.1
Corn	490.2 cd	365-757	686.8 b	493-884	244.5 ef	204-291	473.8
Over-all mean	585.4		708.4		253.3		
			S. zeamais (AMW)				
Wheat	896.8 a	538-1110	729.0 b	546-892	270.8 d	139-468	632.2
Sorghum	619.7 bc	532-684	759.2 ab	639-895	129.8 d	77-174	502.9
Corn	550.3 c	314-683	629.2 bc	480-781	185.5 d	93-244	455.0
Over-all mean	688.9		705.8		195.4		
			S. oryzae (RW)				
Wheat	990.8 a	804-1148	817.0 b	665-1008	234.3 d	200-277	680.7
Sorghum	714.0 b	487-911	813.5 b	623-1084	38.7 e	23-64	522.1
Corn	747.5 b	596-872	559.7 c	334-809	36.3 e	24-68	447.8
Over-all mean	817.4		730.1		103.1		
			S. granarius (GW)				
Wheat	443.8 a	406-502	308.5 b	241-394	112.8 d	75-178	291.7
Sorghum	193.7 c	144-272	151.8 cd	85-217	35.3 e	18-45	126.9
Corn	342.8 b	257-393	110.8 d	59-137	3.0 e	2-5	152.2
Over-all mean	326.8		190.4		53.7		

Means followed by dissimilar letters (within the same population) are significantly different at the 5% level. Lines connecting over-all means indicate nonsignificant differences; others are significantly different.

EXPLANATION OF PLATE I

Mean numbers of progeny of 4 populations of grain weevils produced in wheat, sorghum or corn by parents reared in wheat, sorghum or corn.

Fig. 1. MMW, S. zeamais (Mots.), Mexican population.

Fig. 2. AMW, S. zeamais (Mots.), Arkansas population.

Fig. 3. RW, S. oryzae (Linn.), Kansas population.

Fig. 4. GW, S. granarius (Linn.), Kansas population.

THIS BOOK CONTAINS NUMEROUS PAGES WITH DIAGRAMS THAT ARE CROOKED COMPARED TO THE REST OF THE INFORMATION ON THE PAGE.

THIS IS AS RECEIVED FROM CUSTOMER.

Plate I

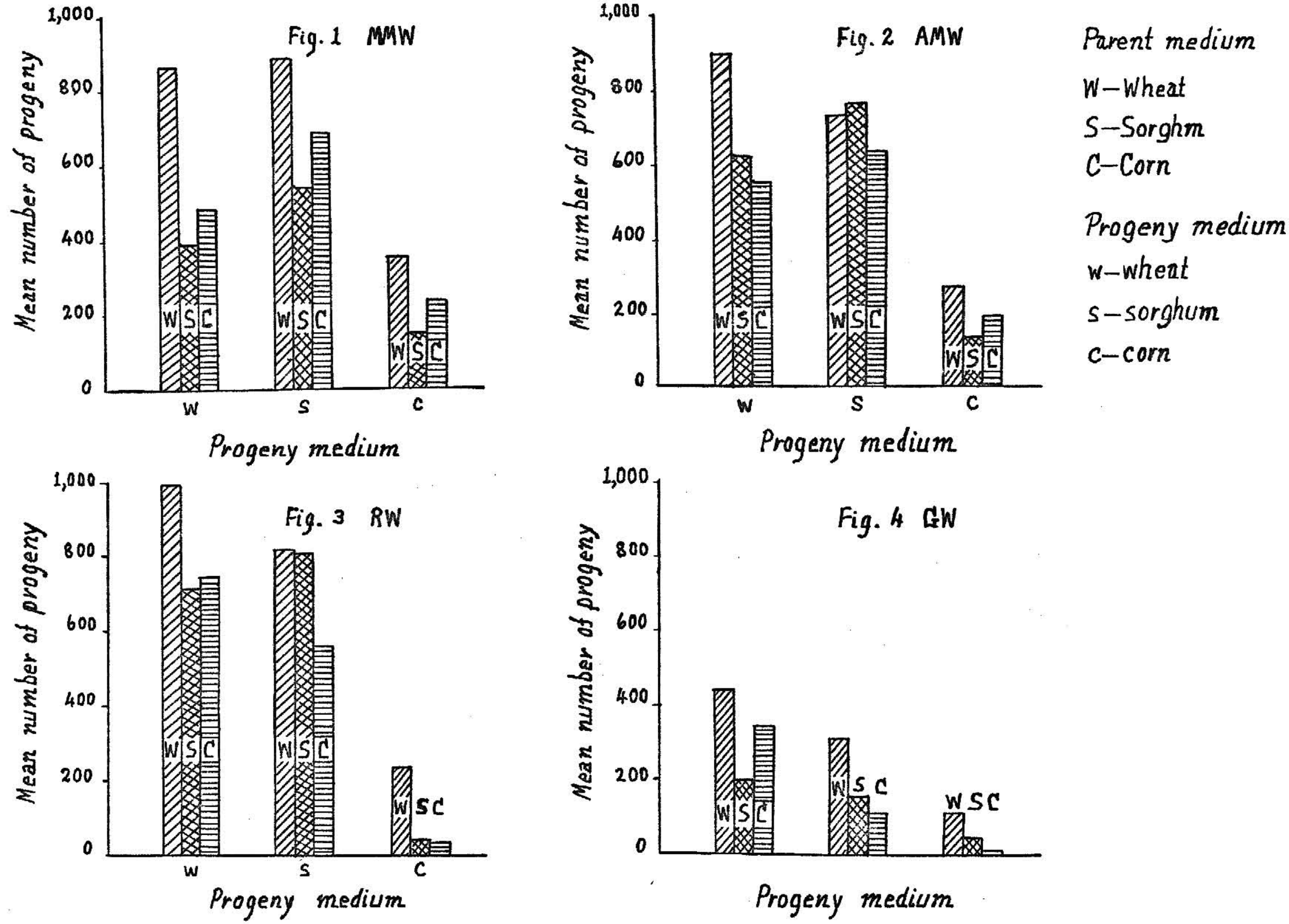


Fig. 1 MMW
Fig. 2 AMW
Fig. 3 RW
Fig. 4 GW
Mean number of progeny
1,000
800
600
400
200
0
w
s
c
W S C
Progeny medium
Parent medium
W—Wheat
S—Sorghm
C—Corn
Progeny medium
w—wheat
s—sorghum
c—corn

in wheat differed significantly from those reared in sorghum or corn; differences were not significant between sorghum and corn. The over-all mean numbers of progeny produced in each grain by parents reared in all grains were 705.8 in sorghum, 688.9 in wheat and 195.4 in corn; the over-all mean number of progeny in corn differed significantly from those produced in wheat or sorghum.

The mean numbers of progeny produced in wheat, sorghum or corn by parents reared in each medium are given in Table 2. Parents from wheat produced significantly different mean numbers of progeny in wheat (896.8), sorghum (729.0) and corn (270.8). Parents from sorghum produced more progeny in sorghum (759.2), significantly different from those produced in corn (129.8) but not from those produced in wheat (619.7). Parents from corn produced more progeny in sorghum (629.2), significantly different from those produced in corn (185.5) but not from those produced in wheat (550.3). The mean numbers of progeny produced in each of the 3 grains, when parents were reared in each grain, are illustrated in Plate I (Fig. 2). Mean numbers of progeny in wheat were 896.8, 619.7 and 550.3 from parents reared in wheat, sorghum and corn, respectively; the latter two means were not significantly different. Mean numbers of progeny in sorghum or corn produced by parents from each grain did not differ significantly; means for progeny in sorghum were 759.2, 729.0 and 629.2 from parents reared in sorghum, wheat and corn, respectively; and means in corn were 270.8, 185.5 and 129.8 from parents reared in wheat, corn and sorghum, respectively.

The Rice Weevil (RW). The over-all mean numbers of progeny produced in all 3 grains by parents reared in wheat, sorghum, or corn were 680.7/ sample for parents reared in wheat, significantly different from the mean numbers produced by parents reared in sorghum (522.1) and corn (447.8); these were not significantly different. There were significant differences in the over-all mean numbers of progeny produced in each grain by parents reared in all grains; average numbers of progeny in wheat, sorghum, and corn were 817.4, 730.1 and 103.1/sample, respectively.

Results of analysis of variance of the mean numbers of progeny produced in wheat, sorghum or corn by parents reared in each grain are shown in Table 2. There were significant differences in mean numbers of progeny in wheat (990.8), sorghum (817.0), and corn (234.3) produced by parents from wheat. Parents from sorghum produced more progeny in sorghum (813.5), significantly different from those produced in corn (38.7), but not from those produced in wheat (741.0). Parents from corn produced significantly different mean numbers of progeny in all grains; the means were 745.5 in wheat, 559.7 in sorghum, and 36.3 in corn. The mean numbers of progeny produced in each of the 3 grains from parents reared in each grain are illustrated in Plate I (Fig. 3). Mean number of progeny produced in wheat was greatest from parents reared in wheat (990.8), significantly different from that of parents reared in corn (747.5) and sorghum (714.0). The mean number of progeny produced in sorghum was greatest from parents reared in wheat (817.0), significantly different from those produced by parents reared in corn (559.7), but not significantly different from those produced by parents reared in sorghum

(813.5). The mean numbers of progeny produced in corn was 234.3 from parents reared in wheat, significantly different from those parents reared in sorghum (38.7) and corn (36.3).

The Granary Weevil (GW). The over-all mean numbers of progeny produced in all 3 grains by parents reared in wheat, sorghum or corn were 291.7, 126.9, and 152.2/sample, respectively; the latter means were not significantly different. There were significant differences in the over-all mean numbers of progeny produced in each grain by parents reared in all 3 grains. For wheat, sorghum and corn they were 326.8, 190.4 and 53.7/sample, respectively.

Shown in Table 2 are the results of the analysis of variance of the mean numbers of progeny produced in wheat, sorghum or corn by parents reared in each medium. The mean numbers of progeny produced in wheat (443.8), sorghum (308.5) and corn (112.8) by parents reared in wheat were significantly different. Parents from sorghum produced significantly more progeny in wheat (193.7) than in corn (35.3) but not significantly more than in sorghum (151.8). The mean numbers of progeny produced in wheat (342.8), sorghum (110.8) and corn (3.0) by parents from corn were significantly different. The mean numbers of progeny produced in each of the 3 grains when parents were reared in each medium are illustrated in Plate I (Fig. 4). The mean numbers of progeny produced in wheat were 443.8, 342.8 and 193.7 from parents reared in wheat, corn and sorghum, respectively; all means were significantly different. Mean numbers of progeny produced in sorghum by parents from wheat, sorghum and corn were 308.5, 151.8 and 110.8, respectively; mean numbers produced in corn by parents from wheat, sorghum and corn were 112.8, 35.3 and 3.0, respectively. Numbers of progeny produced in both sorghum and corn by parents from wheat were significantly different from those produced by parents reared in sorghum and corn; other differences were not significant.

Variation of Progeny Production Among the Four Populations as Influenced by Parent and Progeny Rearing Media. For each insect (strain or species) number of progeny emerged from each of the 3 handled samples (from the previous test) of each grain and from parents reared in each grain were counted every 48 hours after the first adult progeny emergence. Data from only the 3 handled samples were used for greater simplicity of analysis, and because data from these samples were used in evaluating other tests. The analysis of variance among the mean numbers of progeny of the 4 populations were done separately within each progeny rearing medium (wheat, sorghum, or corn).

Progeny Production in Wheat. Table 3 shows mean numbers of progeny produced by each population reared in the same medium. The mean number of progeny for all insects from parents reared in wheat (789.4) was significantly different from those reared in sorghum (476.1) or corn (485.6). Other differences were not significant. Considering the progeny produced by parents from all 3 grains, the RW progeny averaged 825.8; AMW, 645.4; MMW, 546.9; and the GW, 316.7. All means differed significantly except AMW and MMW.

Mean numbers of progeny produced by each of the insects from parents reared in the same medium are illustrated in Plate II (Fig. 1). Parents from wheat produced mean numbers of progeny in wheat in the following order from most to least: RW, AMW, MMW, and GW. GW produced significantly fewer progeny than the other 3 insects. Parents from sorghum produced progeny in wheat in the order from most to least: RW, AMW, MMW, and GW. GW and MMW produced significantly fewer than either the AMW or RW. Parents from corn produced progeny in wheat in the order from most to least: RW, AMW, MMW and GW. Compared to the other insects, RW produced significantly more progeny and GW produced significantly fewer; there was a nonsignificant difference between AMW and MMW.

Progeny Production in Sorghum. The over-all average number of progeny for all insects produced by parents from wheat was 656.6, significantly different from those produced by parents from sorghum, 494.8 or corn, 461.6 (Table 3). Parents reared in sorghum did not differ significantly from parents reared in corn. Considering the progeny produced by parents from all 3 grains, MMW progeny averaged 685.3; RW, 655.6; AMW, 638.8; and GW, 170.9. GW produced significantly fewer progeny than the other 3 insects; differences were nonsignificant in all other cases.

Comparison of mean numbers of progeny produced by each of the insects from parents reared in the same medium are illustrated in Plate II (Fig. 2). Parents from wheat produced mean numbers of progeny in sorghum in order from most to least: MMW, RW, AMW, and GW. Parents from sorghum produced progeny in sorghum in the order from most to least: RW, AMW, MMW, and GW. Parents from corn produced mean numbers of progeny in sorghum in the order from most to least: MMW, AMW, RW, and GW. Parent GW reared in each medium produced significantly fewer progeny than the other 3 insects. Other differences in the same parent rearing medium were not significant.

Progeny Production in Corn. Parents from wheat produced the greatest over-all mean number of progeny (average for all insects, 228.7); parents from corn, 102.7; and parents from sorghum, 78.9 (Table 3). The over-all mean number of progeny from the parents reared in wheat was significantly different from those from parents reared in corn or sorghum. Other differences were not significant. Considering the over-all average of progeny produced by parents from all 3 grains, MMW progeny averaged 236.8; AMW, 165.9; RW, 96.0; and GW, 48.6. All means differed significantly.

Comparison of mean number of progeny produced by each of the insects from parents reared in the same medium is illustrated in Plate II (Fig. 3). Parents from wheat produced mean numbers of progeny in corn which ranked, by insect, from most to least: MMW, RW, AMW, and GW. All means differed significantly except between RW and AMW. Parents from sorghum produced mean numbers of progeny in corn which ranked, by insect: AMW, MMW, GW, and RW. GW and RW each produced significantly fewer progeny than AMW or MMW. Parents from corn produced progeny, ranked by insect: MMW, AMW, RW, and GW. RW and GW each produced significantly fewer than AMW or MMW, and MMW produced significantly greater than AMW.

Table 3. Numbers of progeny produced by 50 parent weevils in wheat, sorghum or corn when parents were reared in each of the 3 grains. Three 250-g samples per test.

Species	Parent rearing medium: Wheat Mean	Wheat Range	Sorghum Mean	Sorghum Range	Corn Mean	Corn Range	Over-all mean
			Progeny in wheat				
MMW	847.0 ab	805-924	359.0 ef	304-389	434.7 de	365-494	546.9
AMW	885.0 ab	538-1108	608.3 cd	532-684	443.0 de	314-597	645.4
RW	985.0 a	804-1148	745.7 bc	654-861	746.7 bc	596-872	825.8
GW	440.0 de	406-502	191.3 f	144-272	318.0 ef	257-389	316.7
Over-all mean	789.4		476.1		485.6		
			Progeny in sorghum				
MMW	878.0 a	647-1007	497.0 c	406-620	681.0 abc	493-884	685.3
AMW	717.0 abc	588-892	662.7 abc	639-708	536.7 bc	452-678	638.8
RW	753.0 ab	665-846	686.0 abc	623-756	527.7 bc	334-809	655.6
GW	278.3 d	241-325	133.3 d	85-178	101.0 d	59-127	170.9
Over-all mean	656.6		494.8		461.6		
			Progeny in corn				
MMW	352.7 a	320-382	125.3 d	66-196	232.3 b	212-271	236.8
AMW	215.0 bc	177-290	132.3 d	77-174	150.3 cd	93-189	165.9
RW	233.7 b	200-277	28.3 e	23-32	26.0 e	24-28	96.0
GW	113.7 d	75-135	29.7 e	18-37	2.3 e	2-3	48.6
Over-all mean	228.7		78.9		102.7		

Means followed by dissimilar letters (within the same progeny rearing medium) are significantly different at the 5% level. Lines connecting over-all means indicate nonsignificant differences; other differences are significant.

EXPLANATION OF PLATE II

Mean numbers of progeny of the 4 populations of grain weevils produced in wheat, sorghum, and corn by parents reared in wheat, sorghum or corn.

M = MMW, *S. zeamais* (Mots.), Mexican population.

A = AMW, *S. zeamais* (Mots.), Arkansas population.

R = RW, *S. oryzae* (Linn.), Kansas population.

G = GW, *S. granarius* (Linn.), Kansas population.

Plate II

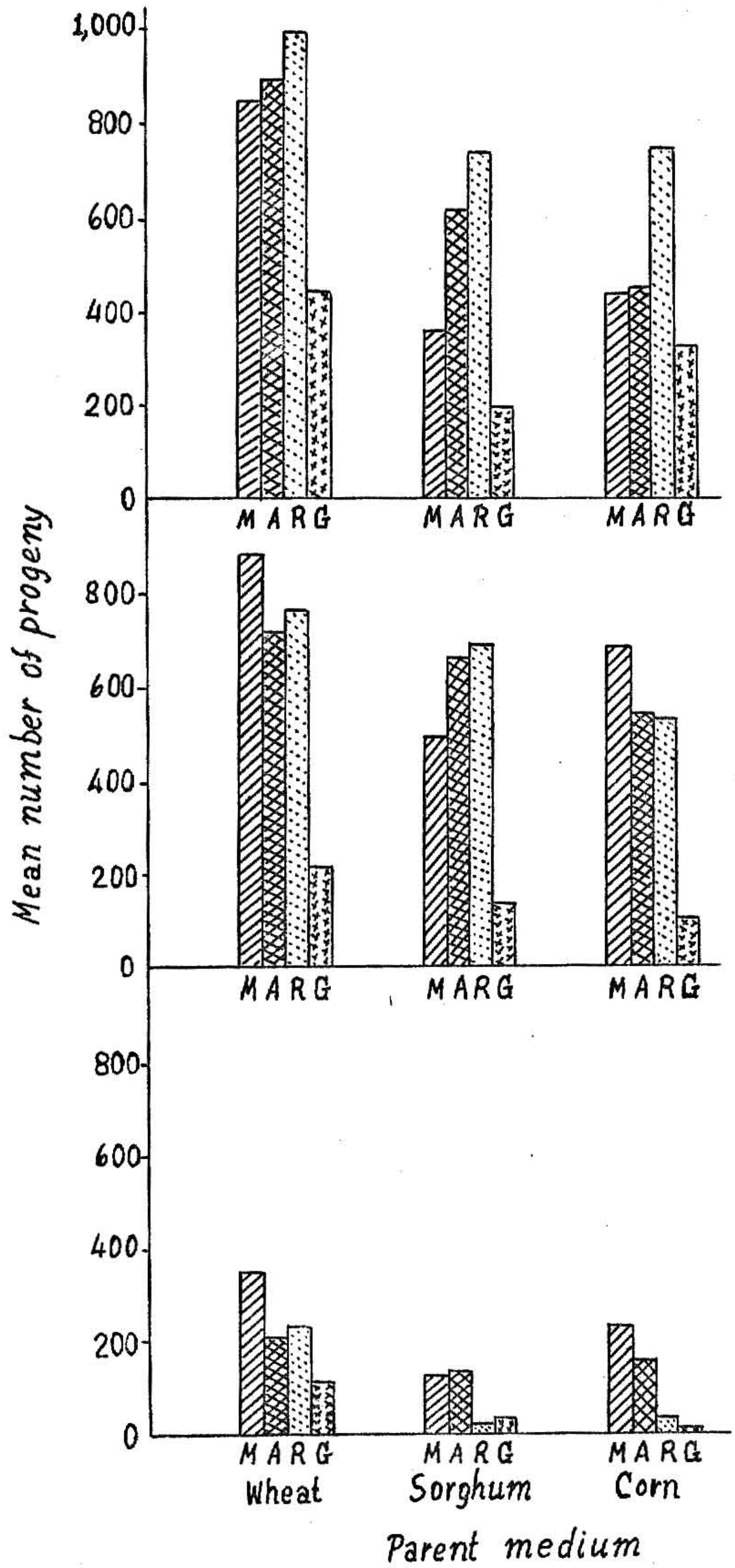


Fig. 1
Progeny in wheat

Fig. 2
Progeny in sorghum

Fig. 3
Progeny in corn

DEVELOPMENTAL PERIOD

Materials and Methods

Developmental periods of the progeny emerged in the "handled" samples (progeny removed each 48 hr) were calculated from the middle of the 6-day parental oviposition period. Three of the 6 replicates in each test were thus treated. Possible error in the range of the developmental period (Table 4) was ± 3 days, but the errors of the means are small due to "cancelling" out of errors by averaging.

Results and Discussion

Effect of Parent and Progeny Rearing Media on Each Population. Mexican Maize Weevil (MMW). Analysis of variance indicated that all parent media (wheat, sorghum and corn) affected the MMW progeny developmental periods (Table 4). The over-all average of all means of developmental periods in all grains when parents were reared in each medium was used as the index of the effectiveness of the parent rearing medium. The over-all mean of the developmental periods was shortest when parents were reared in wheat (34.5 days); intermediate when parents were from corn (36.4 days); and longest when parents were from sorghum (37.5 days). Those means were significantly different. The effectiveness of progeny rearing medium was determined by averaging the 3 means in the same progeny medium from parents reared in all media. Those over-all averages were all significantly different. The mean developmental period was shortest in sorghum (32.9 days), intermediate in wheat (35.5 days) and longest in corn (39.9 days).

Table 4 shows the means of the developmental periods of progeny in each medium when parents were reared in each medium. For progeny reared in wheat and sorghum, developmental periods, from shortest to longest, were when parents were reared in wheat, sorghum, and corn, respectively. As shown in Table 4, not all differences were significant. Progeny reared in corn had shortest, intermediate and longest developmental periods when parents were reared in wheat, corn and sorghum, respectively (all differences were significant).

For parents reared in wheat, sorghum, or corn, the means of the developmental periods of progeny were shortest in sorghum, intermediate in wheat, and longest in corn. All means were significantly different (Table 4).

The shortest mean developmental period of progeny was 32.3 days in sorghum from parents reared in wheat, and the longest was 44.2 days in corn from parents reared in sorghum.

Arkansas Maize Weevil (AMW). Analysis of variance indicated that all parent media (wheat, sorghum and corn) affected AMW progeny developmental periods (Table 4 and Plate III, Fig. 2). The over-all average of all means of developmental periods in all media when parents were reared in each medium was used as the index for the effectiveness of parent rearing medium. The over-all mean of the developmental periods was shortest, from parents reared in wheat (34.9 days), intermediate from parents reared in corn (36.1 days) and longest from parents reared in sorghum (36.8 days); all means were significantly different. The effectiveness of progeny rearing medium was determined by averaging the 3 means in the same medium from parents reared in all grains. The over-all mean developmental period was shortest in sorghum (32.4 days), intermediate in wheat (33.3 days), and longest in corn (42.1 days); all means were significantly different.

The mean of the developmental periods of progeny in each grain when parents were reared in each medium is shown in Table 4. For progeny reared in wheat, developmental periods from shortest to longest were when parents were reared in wheat, corn and sorghum, respectively. Developmental periods of progeny of parents from wheat differed significantly from those when parents were reared in sorghum or corn. There were nonsignificant differences in the mean of progeny developmental periods in sorghum when parents were reared in each medium. For progeny reared in corn, the mean developmental periods from shortest to longest were when parents were reared in wheat, corn and sorghum, respectively. All differences were significant.

For parents reared in wheat, the developmental periods of progeny were significantly shorter in wheat or sorghum than in corn. For parents reared in sorghum or corn the developmental periods of progeny were shortest in sorghum, intermediate in wheat, and longest in corn. All differences were significant.

The shortest mean developmental period of progeny was 32.3 days in wheat from parents reared in wheat, and the longest was 43.8 days in corn when parents were reared in sorghum.

The Rice Weevil (RW). Analysis of variance indicated that parent and progeny rearing media affected the progeny developmental periods (Table 4 and Plate III, Fig. 3). The over-all average of all means of progeny developmental periods in all grains, when parents were reared in each grain, was used as an index for the effectiveness of parent rearing medium. The over-all mean of the developmental periods was significantly shorter (38.1 days) when parents were reared in wheat than when reared in sorghum or corn (39.9 days). The effectiveness of progeny rearing medium was determined by averaging the 3 means in the same medium for parents reared in all grains. The mean developmental period was shortest in wheat (34.2 days), intermediate in sorghum (35.6 days) and longest in corn (48.1 days). All means were significantly different.

The means of progeny developmental period in each medium from parents reared in each grain are also given in Table 4. Means of progeny developmental period in wheat or sorghum were not significantly different when parents were reared in each grain. For progeny reared in corn, the developmental period was significantly shorter when parents were reared in wheat than those means when parents were in sorghum or corn.

For parents reared in wheat, sorghum or corn, mean developmental periods of progeny were shortest in wheat, intermediate in sorghum, and longest in corn. Significant differences existed between the means in wheat and sorghum but not in other cases.

The shortest mean developmental period of progeny averaged 33.7 days in wheat when parents were reared in wheat, and the longest was 50.0 days in corn when parents were reared in corn.

The Granary Weevil (GW). The analysis of variance indicated that parent rearing media had no significant effect on the progeny developmental periods. The over-all average of all means of developmental periods in all grains when parents were reared in each grain was shortest when parents were

Table 4. Developmental period (days) of the weevil progeny in wheat, sorghum or corn, from parents reared in each of the 3 grains (13.5% moisture content, 68±2% RH and 27±1°C).

Parent rearing medium	Wheat Mean	Wheat Range (±3)	Sorghum Mean	Sorghum Range (±3)	Corn Mean	Corn Range (±3)	Over-all Mean
			S. zeamais (MMW)				
Wheat	34.2 d	25-51	32.3 e	25-49	36.9 c	25-51	34.5
Sorghum	35.9 c	27-53	32.4 e	25-53	44.2 a	27-57	37.5
Corn	36.5 c	29-59	34.0 d	25-51	38.7 b	27-55	36.4
Over-all mean	35.5		32.9		33.9		
			S. zeamais (AMW)				
Wheat	32.3 f	25-49	32.7 ef	25-51	39.6 c	25-59	34.9
Sorghum	34.0 d	26-51	32.4 ef	25-51	43.8 a	29-61	36.8
Corn	33.4 de	25-49	32.1 f	27-49	42.7 b	27-59	36.1
Over-all mean	33.3		32.4		42.1		
			S. oryzae (RW)				
Wheat	33.7 d	27-49	35.6 cd	27-55	44.9 b	29-61	38.1
Sorghum	34.2 cd	27-49	35.6 cd	26-55	49.2 a	33-69	39.9
Corn	34.0 d	27-51	35.7 c	27-53	50.0 a	35-63	38.9
Over-all mean	34.2		35.6		48.1		
			S. granarius (GW)				
Wheat	38.0 d	29-59	41.8 d	33-67	49.3 bc	33-69	43.0
Sorghum	40.0 d	33-51	42.6 cd	35-61	51.4 ab	37-71	44.6
Corn	40.7 d	31-63	44.2 cd	33-65	56.8 a	39-81	47.2
Over-all mean	39.5		42.9		52.5		

Means followed by dissimilar letters are significantly different at the 5% level (within the same population). Lines connecting over-all means indicate nonsignificant differences; other differences are significant.

EXPLANATION OF PLATE III

Mean progeny developmental periods of the 4 populations of grain weevils reared in wheat, sorghum or corn from parents reared in wheat, sorghum or corn.

Parent rearing media: W - wheat, S - sorghum and C - corn.

Progeny rearing media: w - wheat, s - sorghum and c - corn.

Fig. 1. MMW, *S. zeamais* (Mots.), Mexican population.

Fig. 2. AMW, *S. zeamais* (Mots.), Arkansas population.

Fig. 3. RW, *S. oryzae* (Linn.), Kansas population.

Fig. 4. GW, *S. granarius* (Linn.), Kansas population.

Plate III

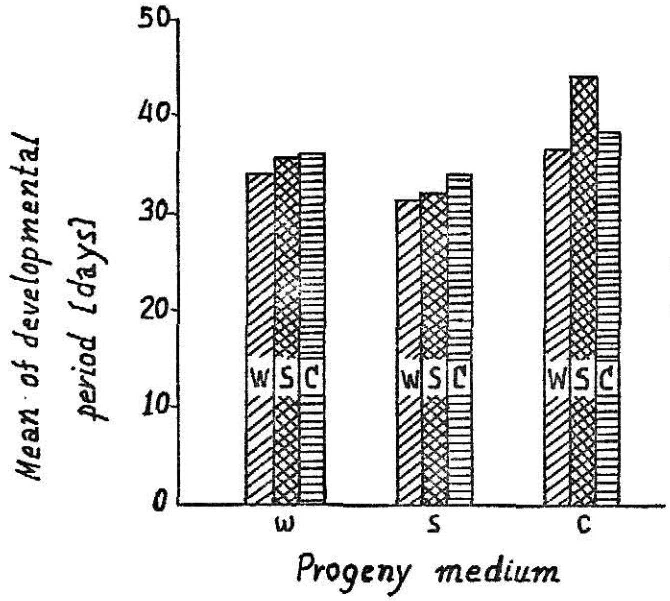


Fig. 1
MMW

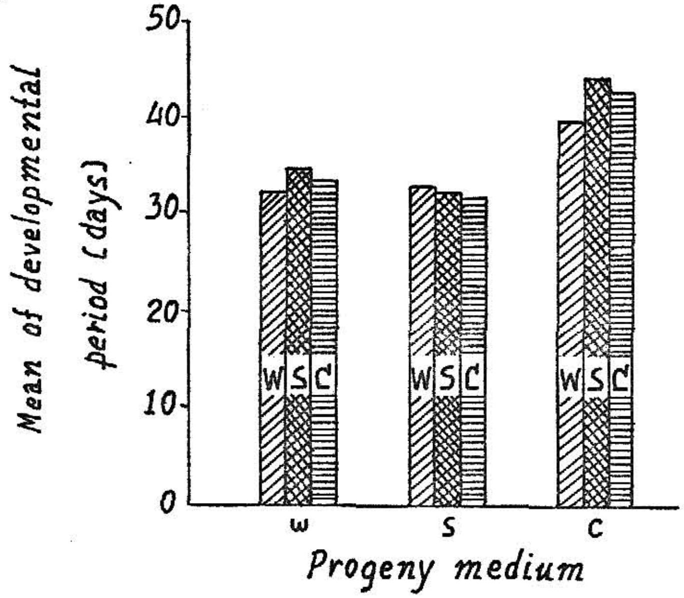


Fig. 2
AMW

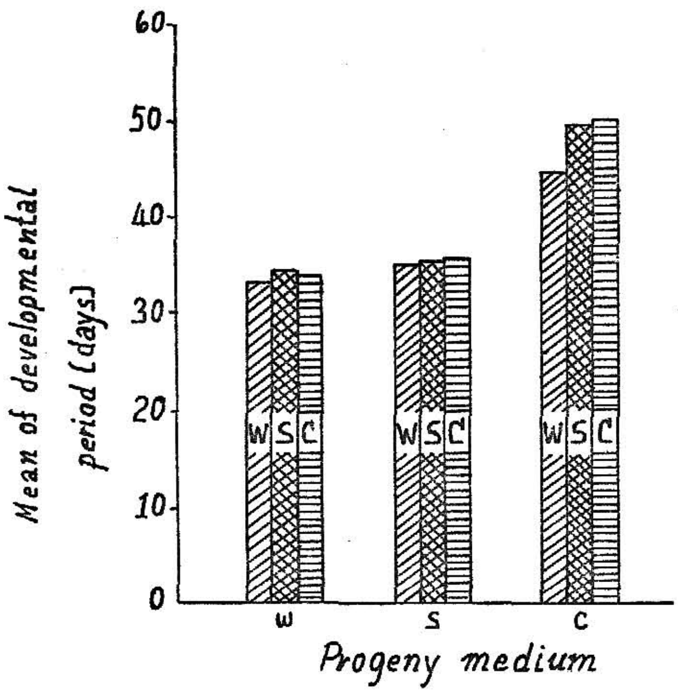


Fig. 3
RW

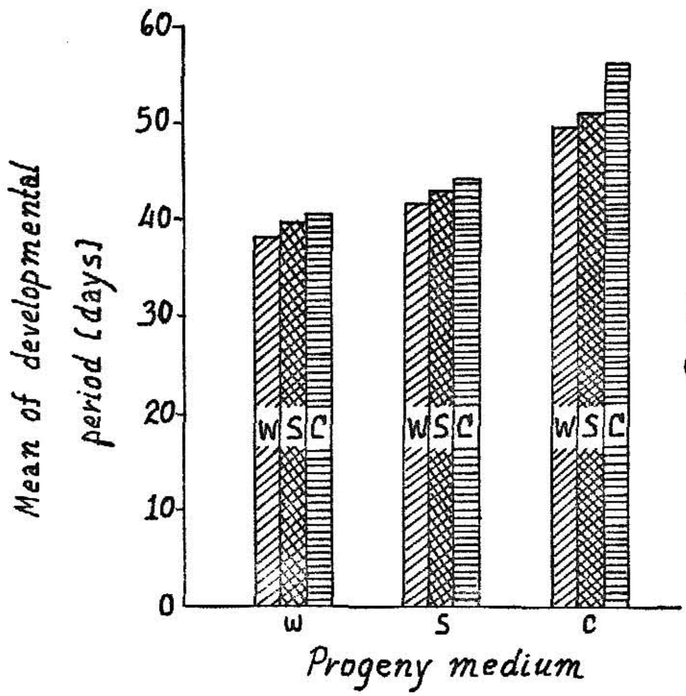


Fig. 4
GW

reared in wheat (43.0 days), intermediate when parents were reared in sorghum (44.6 days) and longest when parents were reared in corn (47.2 days) (Table 4). The effectiveness of progeny rearing media was determined by averaging the 3 means in the same medium for parents reared in all grains. The over-all means of developmental periods were shortest in wheat (39.5 days), intermediate in sorghum (42.9 days) and longest in corn (52.5 days). The mean in corn differed significantly from those in wheat or sorghum.

Table 4 shows the means of the developmental periods of the progeny in each medium when parents were reared in each grain. For progeny reared in wheat, sorghum, or corn, the developmental periods from shortest to longest were when parents were reared in wheat, sorghum and corn, respectively. Not all differences were significant.

For parents reared in wheat, sorghum, or corn, the mean developmental period was shortest in wheat, intermediate in sorghum and longest in corn. The means in corn differed significantly from those means in wheat and sorghum.

The shortest mean developmental period of progeny was 38.0 days in wheat when parents were reared in wheat, and the longest, 56.8 days, in corn when parents were reared in corn.

Variation of Progeny Developmental Periods Among the 4 Populations as Influenced by Parent and Progeny Rearing Media. The progeny developmental periods of the 4 populations were compared as influenced by parent and progeny rearing media. The analysis of variance was done on the mean days of development within the same progeny rearing medium.

Development in Wheat. Analysis of variance indicated that parent rearing media affected progeny developmental period (Table 5 and Plate IV, Fig. 1). The over-all average developmental periods of the progeny of all 4 populations were shortest (34.8 days) when parents were reared in wheat, intermediate (36.1 days) when parents were reared in corn, and longest (36.2 days) when parents were reared in sorghum. The average for parents reared in wheat was significantly different from those for parents reared in corn and sorghum.

For each population, the over-all average developmental periods of progeny from parents reared in all media were 33.3 days for AMW, 34.5 days for RW, 35.5 days for MMW, and 39.6 days for GW. All means were significantly different.

For each parent rearing medium, the progeny developmental periods were shortest for AMW and longest for GW; the relative developmental periods of MMW and RW were inconsistent. Significant differences are indicated in Table 5.

Development in Sorghum. In sorghum the over-all average developmental periods of the progeny of all 4 populations were shortest, 35.6 days, when parents were reared in wheat; intermediate, 35.8 days, when parents were reared in sorghum; and longest, 36.8 days, when parents were reared in corn. When parents were reared in corn the average was significantly different from those of parents reared in sorghum and wheat.

For each population, the over-all average progeny developmental periods when parents were reared in all media were 32.4 days for AMW,

Table 5. Mean progeny developmental periods (days) of 4 weevil populations in wheat, sorghum or corn from parents reared in each of the 3 grains (13.5% moisture content, 27±1°C and 68±3% RH).

Species	Parent rearing medium			Over-all
	Wheat	Sorghum	Corn	mean
		Development in wheat		
MMW	34.2 de	35.9 c	36.5 c	35.5
AMW	32.3 f	34.0 de	33.4 e	33.2
RW	34.8 d	34.8 d	33.0 de	34.5
GW	38.0 b	40.0 a	40.7 a	39.5
Over-all mean	34.8	36.2	36.1	
		Development in sorghum		
MMW	32.3 d	32.4 d	34.0 cd	32.9
AMW	32.7 d	32.4 d	32.1 d	32.4
RW	35.6 c	35.6 c	35.7 c	35.6
GW	41.8 b	42.6 ab	44.2 a	42.9
Over-all mean	35.6	35.8	36.8	
		Development in corn		
MMW	36.9 f	44.2 cde	38.7 ef	39.9
AMW	39.6 ef	43.8 cde	42.7 def	42.0
RW	49.2 bcd	49.2 bcd	50.0 bc	49.5
GW	49.3 bcd	51.4 ab	56.8 a	52.5
Over-all mean	43.8	47.2	47.1	

Means followed by dissimilar letters are significantly different at the 5% level (within the same progeny rearing medium). Lines connecting over-all means indicate nonsignificant differences; other differences are significant.

EXPLANATION OF PLATE IV

Mean developmental periods of the 4 populations of grain weevils when reared in wheat, sorghum, or corn from parents reared in wheat, sorghum, or corn.

M = MMW, *S. zeamais* (Mots.) of a Mexican population.

A = AMW, *S. zeamais* (Mots.) of an Arkansas population.

R = RW, *S. oryzae* (Linn.), the rice weevil.

G = GW, *S. granarius* (Linn.), the granary weevil.

Plate IV

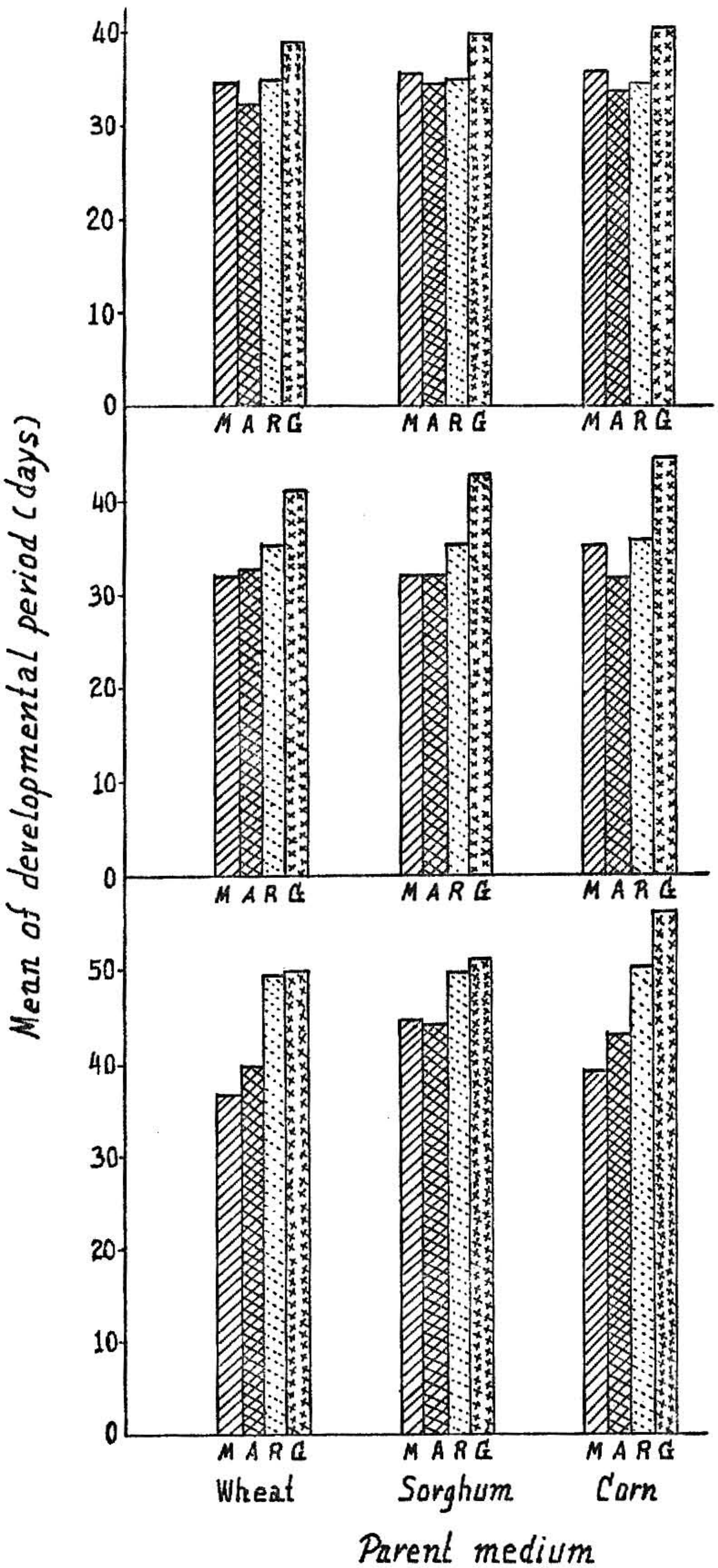


Fig. 1
Development in wheat

Fig. 2
Development in sorghum

Fig. 3
Development in corn

32.9 days for MMW, 35.6 days for RW, and 42.9 days for GW. Differences were significant except between AMW and MMW.

For each parent rearing medium, the developmental periods were shortest for MMW and longest for GW. The relative developmental periods for all 4 populations when parents were reared in each of the 3 grains are presented in Table 5.

Development in Corn. The over-all average developmental periods of the progeny of all populations were shortest, 43.7 days, when parents were from wheat; intermediate, 47.1 days, when parents were from corn; and longest, 47.2 days, when parents were from sorghum. The average for parents reared in wheat was significantly different from those of parents reared in corn or sorghum.

For each population, the over-all average developmental periods of progeny from parents reared in all media were 39.9 days for MMW, 42.1 days for AMW, 49.5 days for RW, and 52.5 days for GW. Means for MMW and AMW were significantly shorter than the means for RW and GW.

For each parent rearing medium, the progeny developmental periods were shortest for MMW and longest for GW. All other differences among means of developmental periods of the 4 populations are shown in Table 5.

SIZE OF ADULTS

Materials and Methods

All parent and progeny weevils from the previous studies were preserved in alcohol and 3 random samples of 10 insects each were selected from each parent and progeny group for measurements of size.

One elytron of each insect was measured dorso-longitudinally between the anterior margin (excluding the thin carina) to the tip of the posterior margin. All measurements were made using a Bausch and Lomb binocular microscope with an ocular micrometer. Magnification used was 45X. A total of 360 parent weevils and 1,057 progeny weevils of the 4 populations from 3 different grains were measured (only 7 GW progeny emerged in corn from parents reared in corn).

Results and Discussion

Effects of Parent and Progeny Rearing Media on Progeny Elytron Length in Each Population. Statistical analysis indicated no significant correlation between parent elytron length and progeny elytron length (i.e., larger parents did not produce larger progeny in all grains). The progeny elytron lengths were influenced by both parent and progeny rearing media. The mean elytron lengths of progeny for each population produced in wheat, sorghum or corn by parents from each of the 3 grains are given in Table 6.

Mexican Maize Weevil (MMW). The over-all average of all mean elytron lengths of progeny in all grains from parents reared in each grain was used as the index of the effect of parent rearing medium. Analysis of variance indicated that parent rearing medium had no effect on the progeny elytron length; the over-all average of the mean elytron lengths of progeny were 1.69 mm from parents reared in sorghum or wheat, and 1.70 mm from parents reared in corn. The rearing media of the progeny affected their size. The over-all average of the mean elytron lengths of progeny reared in the same medium from parents reared in all grains was significantly greater in corn (1.79 mm) than the average lengths in sorghum (1.65 mm) or in wheat (1.64 mm).

Mean elytron lengths in corn were significantly greater than in sorghum or wheat regardless of parent rearing medium, whereas the means in sorghum and wheat were not significantly different.

The range in the mean lengths was 1.63 mm in wheat (parents from sorghum) or in sorghum (parents from wheat) to 1.81 mm in corn (parents from corn).

Arkansas Maize Weevil (AMW). The over-all averages of mean elytron lengths of progeny in all grains were 1.77 mm from parents reared in wheat, which was significantly greater than from parents reared in corn, 1.74; and sorghum, 1.73 mm. The effectiveness of progeny rearing media was indicated by the over-all averages of all mean elytron lengths in each grain from parents reared in all 3 grains. The over-all average elytron lengths of progeny were longest in corn, 1.84 mm; intermediate in wheat, 1.72 mm; and shortest in sorghum, 1.68 mm. All means were significantly different.

Mean elytron lengths in corn were significantly greater than in wheat or in sorghum when parents were reared in each medium. The means in wheat and sorghum were not significantly different.

For progeny reared in wheat, mean elytron length was significantly greater when parents were reared in wheat, than when reared in sorghum.

The range in the mean length was 1.66 mm in sorghum (parents from corn) to 1.86 mm in corn (parents from corn).

The Rice Weevil (RW). Analysis of variance indicated that both parent and progeny rearing media affected progeny size. The over-all averages of mean elytron lengths of progeny in all grains from parents reared in each grain was 1.60 mm from parents reared in wheat, which was significantly longer than from parents reared in corn, 1.57 mm; or sorghum, 1.56 mm. For the progeny rearing media, the over-all average of the means of elytron lengths of progeny in each grain when parents were reared in all grains was 1.67 mm in corn, which was significantly greater than when parents were reared in wheat or sorghum (1.53 mm).

Mean elytron lengths in corn were significantly greater than in wheat or sorghum when parents were reared in each grain, whereas means in wheat and sorghum were not significantly different.

For progeny reared in wheat, the mean elytron length was significantly greater when parents were from wheat. For progeny reared in corn, mean elytron length was significantly greater when parents were from wheat than when from corn or sorghum.

The range in mean elytron length was 1.51 mm in wheat (parents from sorghum or corn) to 1.71 mm in corn (parents from wheat).

The Granary Weevil (GW). Parent rearing media had no effect on the progeny elytron lengths. The over-all average of the means of progeny produced in all grains when parents were reared in each medium was 1.76 mm from parents reared in wheat, 1.74 mm from parents reared in corn, and 1.73 mm from parents reared in sorghum. The effectiveness of progeny rearing media was indicated by the over-all average of all mean elytron lengths of progeny in each grain when parents were reared in all grains. The mean elytron lengths were longest in wheat (1.79 mm), intermediate in corn (1.76 mm), and shortest in sorghum (1.68 mm). All means were significantly different.

Table 6. Progeny elytron length (mm) in 4 weevil populations reared in wheat, sorghum or corn from parents reared in each of the 3 grains (13.5% moisture content, 68±3% RH, 27±1°C).

Parent rearing medium	Progeny elytron length (mm) when reared in						Over-all mean
	Wheat		Sorghum		Corn		
	Mean	Range	Mean	Range	Mean	Range	
			S. zeamais (MMW)				
Wheat	1.64 b	1.43-1.80	1.63 b	1.40-1.93	1.80 a	1.45-1.98	1.69
Sorghum	1.63 b	1.48-1.80	1.67 b	1.40-1.92	1.77 a	1.57-1.96	1.69
Corn	1.65 b	1.43-1.80	1.64 b	1.40-1.93	1.81 a	1.63-1.96	1.70
Over-all mean	1.64		1.65		1.79		
			S. zeamais (AMW)				
Wheat	1.75 b	1.57-1.91	1.71 bc	1.50-1.86	1.85 a	1.63-2.10	1.77
Sorghum	1.69 c	1.47-1.89	1.68 c	1.46-1.83	1.81 a	1.42-2.03	1.73
Corn	1.71 bc	1.53-1.86	1.66 c	1.47-1.88	1.86 a	1.63-2.00	1.74
Over-all mean	1.72		1.68		1.84		
			S. oryzae (RW)				
Wheat	1.57 c	1.20-1.93	1.53 cd	1.37-1.67	1.71 a	1.50-1.86	1.60
Sorghum	1.51 d	1.37-1.67	1.54 cd	1.33-1.76	1.64 b	1.47-1.90	1.56
Corn	1.51 d	1.30-1.65	1.53 cd	1.38-1.73	1.67 ab	1.47-1.93	1.57
Over-all mean	1.53		1.53		1.67		
			S. granarius (GW)				
Wheat	1.80 a	1.47-1.93	1.68 cd	1.43-1.96	1.81 a	1.57-2.11	1.76
Sorghum	1.77 a	1.53-1.99	1.70 cd	1.43-1.90	1.76 ab	1.60-1.93	1.73
Corn	1.81 a	1.53-1.99	1.70 cd	1.47-1.90	1.72 bc	1.62-1.83	1.74
Over-all mean	1.79		1.68		1.76		

Means followed by dissimilar letters are significantly different at the 5% level (within the same population). Lines connecting over-all means (within populations) indicate nonsignificant differences; other means are significantly different.

Mean elytron length in sorghum was significantly shorter than those means in wheat and sorghum, when parents were reared in each of the 3 grains. Differences between means in sorghum and corn were nonsignificant (both parents from corn).

The range in mean elytron lengths was 1.66 mm in sorghum (parents from sorghum) to 1.81 mm in corn (parents from wheat), or in wheat (parents from corn).

Variation in Parent Elytron Length Among the Four Populations Reared in Wheat, Sorghum, or Corn. The over-all average of mean elytron lengths of all 4 populations within each medium was used as the index for comparing effect of rearing media on parent size (Table 7). The mean lengths of elytron were longest in corn (1.82 mm), intermediate in wheat (1.70 mm), and shortest in sorghum (1.66 mm); all means differed significantly. The variation among the 4 populations was indicated by the over-all average of the mean elytral lengths in all media for each population: 1.78 mm for the GW, 1.75 mm for AMW, 1.72 mm for MMW, and 1.64 mm for the RW. The RW differed significantly from all other populations. The GW differed significantly from MMW but not from AMW.

The elytron lengths of the weevils from each population in each rearing medium ranked from longest to shortest: GW, AMW, MMW, and RW in wheat: GW, AMW and MMW, and RW in sorghum; and AMW, MMW, GW, and RW in corn.

Table 7. Parent elytron length (mm) in 4 weevil populations reared in wheat, sorghum, or corn of 13.5% moisture content at 27±1°C and 68±3% RH.

Species	Culture medium						Over-all mean
	Wheat		Sorghum		Corn		
	Mean	Range	Mean	Range	Mean	Range	
MMW	1.66 c	1.53-1.80	1.67 c	1.40-1.83	1.85 a	1.70-1.96	1.72
AMW	1.73 b	1.46-1.88	1.67 c	1.53-1.83	1.86 a	1.65-2.00	1.75
RW	1.59 d	1.63-1.93	1.59 d	1.47-1.83	1.75 b	1.60-1.93	1.64
GW	1.83 a	1.63-1.93	1.70 bc	1.50-1.86	1.84 a	1.64-2.03	1.78
Over-all mean	1.70		1.66		1.82		

Means followed by dissimilar letters are significantly different at the 5% level. Line connecting over-all means indicates nonsignificant differences.

KERNEL WEIGHT LOSSES AND WEEVIL WEIGHTS

Materials and Methods

Wheat, sorghum and corn used were obtained from cleaned stock culture grain. Most dockage was removed by using a U. S. Standard sieve of 9 meshes/inch for wheat and sorghum, and 8 meshes/inch for corn. The moisture content of the grain (Motomco Moisture Meter) ranged from 13-14%. Approximately 300 kernels of wheat or sorghum, or 40 kernels of corn were placed in each 48x48x48-mm plastic box with 60-mesh brass screen in the lid. Five boxes of each grain were prepared for each population. These boxes of grain were allowed to equilibrate for 30 days in the rearing room at 68±3% RH and 27±1°C. The 4 populations of the grain weevil, Mexican maize weevil (MMW), Arkansas maize weevil (AMW), the rice weevil

(RW) and the granary weevil (GW) reared in each grain were obtained from the stock cultures. Ten active 7 to 14-day-old adult females and one male from each population cultured in each grain were introduced into each of the 5 boxes of the same grain for oviposition (transferred by Schuco vacuum tweezer). The 7 to 14-day-old females were assumed to be mated, but the single male was included for mating with possible unmated females. Each box of grain was observed daily for 3 days to locate unbroken kernels with single eggplugs. No eggplug stains were used; eggplugs were located with the use of a binocular microscope. The individual kernels with single eggplugs were allowed to remain over night in the rearing room and were weighed using a Mettler Analytical Balance, Type H-16. Weighed wheat and sorghum kernels were held in the rearing room individually in #2 gelatin capsules and corn kernels were held individually in small plastic boxes (20x20x20 mm) with fine screen lids. Daily observations for newly-emerged adults from these kernels were begun 25 days from the beginning of the oviposition period; each newly-emerged adult was separated from its host and placed in a #2 gelatin capsule and kept in a small airtight metal container. The adult weevil was inactivated by placing the container on the ice for 45 min, then its weight was determined by using a CAHN Electrobalance, Model M-10. The kernel from which the weevil emerged with fecal material, exuviae, etc., remaining inside, was weighed individually within a week after the adult emerged; in the meantime each kernel remained in the rearing room to prevent moisture change. Observations for newly-emerged adults ceased after 12 wk.

Results and Discussion

The data are presented in Table 8 and Plate V. Too few GW and RW developed in corn kernels for statistical analysis. The over-all average of mean weight losses per kernel caused by all kinds of weevils in sorghum was 13.30 mg, not significantly different from weight losses in wheat, 13.13 mg. The over-all average of mean kernel weight losses in wheat and sorghum revealed that the GW caused the greatest average losses, 15.03 mg, which differed significantly from the other populations except MMW which caused average losses of 14.37 mg. The RW caused significantly smaller over-all losses (10.3 mg) than all other populations. AMW caused average losses (13.18 mg) which were intermediate and differed significantly from all other populations.

In both wheat and sorghum the insects ranked in mean kernel weight loss caused from most to least: GW, MMW, AMW and RW. Significant differences are indicated in Table 8.

In corn, with sufficient numbers of only MMW and AMW developing, the MMW caused only slightly greater mean kernel weight losses than AMW.

Kernel Weight Losses Caused by Each Population in Different Grains. MMW caused kernel weight losses in corn twice that in wheat or sorghum. AMW-caused losses were similar. The RW caused significantly greater kernel weight losses in sorghum than in wheat; the reverse was true for the GW.

Mean Percent Weight Losses to Individual Kernels. The average of the mean percent weight losses caused by all of the 4 populations in sorghum (46.3 mg) was significantly greater than those in wheat (38.7 mg).

Percent Kernel Weight Losses Caused by Each Weevil Population in Wheat and Sorghum. The means of the percent kernel weight loss in wheat and sorghum were averaged and this was used as the index for comparing the weevil populations. The GW caused the greatest average percent weight loss (47.5%), which differed significantly from that caused by AMW and RW, but not MMW. The RW caused a significantly smaller average percent loss (33.5%). Percent weight losses caused by MMW (45.7%) and AMW (43.3%), were not significantly different.

Percent Kernel Weight Losses Caused by Each Population in Each Grain. The populations ranked as follows in causing percent kernel losses to wheat or sorghum: GW, MMW, AMW and RW; significant differences are indicated in Table 8.

Percent corn kernel weight loss caused by MMW and AMW were similar. The mean percent weight losses to corn kernels were much less, due to larger size, even though the actual kernel weight losses were greater than in the other two grains.

The MMW caused the greatest mean percent kernel weight loss in sorghum; this differed significantly from that in corn, but not from that in wheat. AMW caused a greater mean percent weight loss in sorghum, and least in corn, with all means differing significantly. The RW and the GW caused significantly greater mean percent weight losses in sorghum than in wheat.

Weevil Weights. The mean wet weight of each newly-emerged adult weevil from the kernels discussed above were recorded. Over-all average of the mean weights of the adult weevils of all 4 populations reared in wheat (2.18 mg) was significantly greater than when reared in sorghum (1.95 mg). Over-all average of the means of weights of adults reared in wheat and sorghum indicated that AMW was heaviest (2.26 mg), and differed significantly from GW and RW, but not from MMW. The RW was significantly

Table 8. Weight losses of individual kernels of wheat, sorghum or corn caused by single weevils; and weights of newly-emerged adult weevils.

Species	Culture medium	Mean initial wt of kernel (mg)	Weight loss/kernel (mg)		Mean % wt loss/ kernel (mg)	Wet wt of emerged adults (mg)	
			Mean	Range		Mean	Range
MMW	Wheat	33.2	14.2 cd	10.5-21.0	43.0 bcd	2.19 c	1.58-2.96
	Sorghum	30.1	14.5 bc	10.1-20.5	48.2 ab	2.22 c	1.59-2.76
	Corn	334.1	32.0 a	15.1-45.7	9.6 f	2.95 a	2.36-3.88
AMW	Wheat	33.3	13.0 c	7.7-18.2	38.9 cd	2.41 b	1.99-2.95
	Sorghum	28.1	13.4 cd	8.0-18.1	47.8 ab	2.11 c	1.20-2.60
	Corn	333.1	31.6 a	21.4-44.5	9.5 f	3.11 a	2.52-3.73
RW	Wheat	32.5	9.6 f	7.5-20.8	29.5 e	1.68 e	1.27-2.27
	Sorghum	29.5	11.0 e	7.7-14.9	37.6 d	1.68 e	1.26-2.25
GW	Wheat	36.2	15.7 b	11.0-22.3	43.5 bc	2.47 b	1.88-3.12
	Sorghum	28.2	14.3 c	10.7-20.0	51.5 a	1.81 d	1.04-2.20

Means followed by dissimilar letters are significantly different at the 5% level (within the same column).

EXPLANATION OF PLATE V

Mean weight losses of individual kernels of wheat, sorghum or corn caused by single insects from the beginning of development to adult emergence, and mean wet weight of emerged adult weevils.

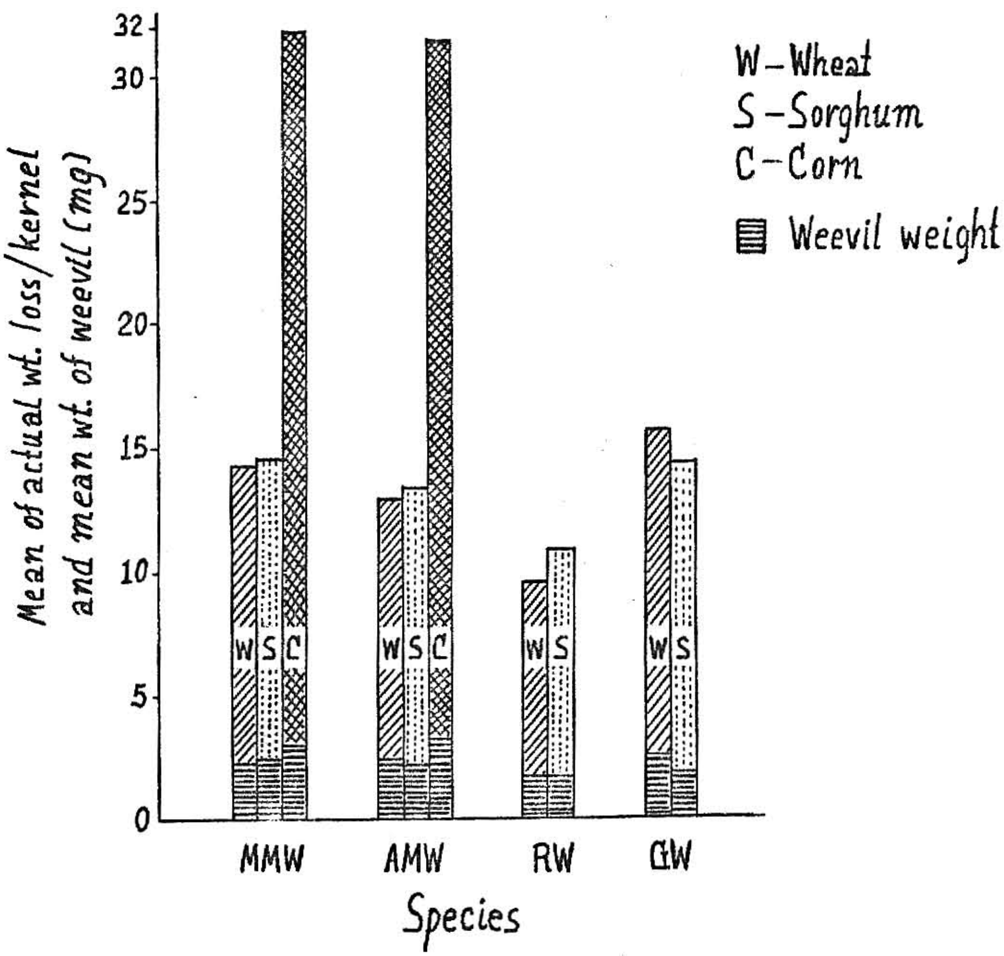
MMW, *S. zeamais* (Mots.), Mexican population.

AMW, *S. zeamais* (Mots.), Arkansas population.

RW, *S. oryzae* (Linn.), Kansas population.

GW, *S. granarius* (Linn.), Kansas population.

Plate V


Mean of actual wt. loss/kernel and mean wt. of weevil (mg)
32
30
25
20
15
10
5
0
W S C
W S C
W S
W S
MMW
AMW
RW
GW
Species
W - Wheat
S - Sorghum
C - Corn
Weevil weight

lighter (1.68 mg) than adults of all other populations. Differences between the weights of the MMW (2.20 mg) and the GW (2.13 mg) were not significant.

In wheat the mean weevil weights, in the order from heaviest to lightest, were of the GW, AMW, MMW and RW. Significant differences are indicated in Table 8.

In sorghum the weevils, from heaviest to lightest, were MMW, AMW, GW, and RW, and in corn AMW was only slightly heavier than MMW.

The MMW was heaviest in corn and lightest in wheat; mean weight in corn was significantly different from mean weights in wheat and sorghum. The AMW was heaviest in corn, intermediate in wheat and lighest in sorghum; all means were significantly different. The RW had similar weights in wheat and sorghum, and the GW was significantly heavier in wheat than in sorghum.

EFFECT OF QUANTITIES OF GRAINS ON REPRODUCTION OF THE RICE WEEVIL

Materials and Methods

The wheat, sorghum and corn used were obtained from the cleaned stock culture media. Six different sizes of samples of each were used in this experiment and 5 replicates were prepared for each size of sample. Wide-mouth quart jars with both 40-mesh screen and kelthane-treated filter paper in the lid were used as the containers for both 500-gram and 625-gram samples; similar pint jars were used for 8, 25, 125 and 250-gram samples. The grain moisture content ranged from 13% to 14%. The samples were allowed to equilibrate for 30 days in the rearing room at $27{\pm}1^{\circ}C$ and

68±3% RH. All parent rice weevils used were reared in corn. Fifty active, unsexed, 7-to-14-day-old adults were introduced into each replicate of each grain for 6 days oviposition, then all adults were removed and the infested samples were held in the rearing room. Daily observations for the first emergence of adult progeny were begun 27 days after the beginning of the oviposition period. Progeny were removed by using a U. S. Standard sieve with 9 meshes/inch for wheat and sorghum samples, and 8 meshes/inch for corn samples. The adult progeny were removed and counted three times a week. The counts were stopped after a 7-day period with no emergence of progeny, or in cases of a few adults continuing to emerge, counts were stopped just before 2nd generation progeny were expected.

Results and Discussion

The mean number of progeny from the 5 replicates of each sample size of each grain was used as the index for comparing the effect of the grain quantity. The results are presented in Table 9, and illustrated in Plate VI. Statistically, the mean numbers of progeny in all sizes of samples of each grain differed significantly except between 8 and 25, and 125 and 250-g samples of corn; between 25 and 125, and among 250, 500, and 625-g samples of wheat; and among 125, 250, 500 and 625-g samples of sorghum. Results indicated that statistically 250 g of wheat or sorghum (approx. 9500 kernels for each) were sufficient for maximum reproduction of 50 unsexed rice weevils; however, the number of progeny increased as grain quantity increased to 625 g. For corn, significant differences among mean numbers of progeny from 250, 500 and 625 g of grain indicated that the 625-g samples

Table 9. Numbers of progeny produced by 50 unsexed rice weevils, in different size samples of wheat, sorghum or corn (5 replicates, 6-day oviposition period).

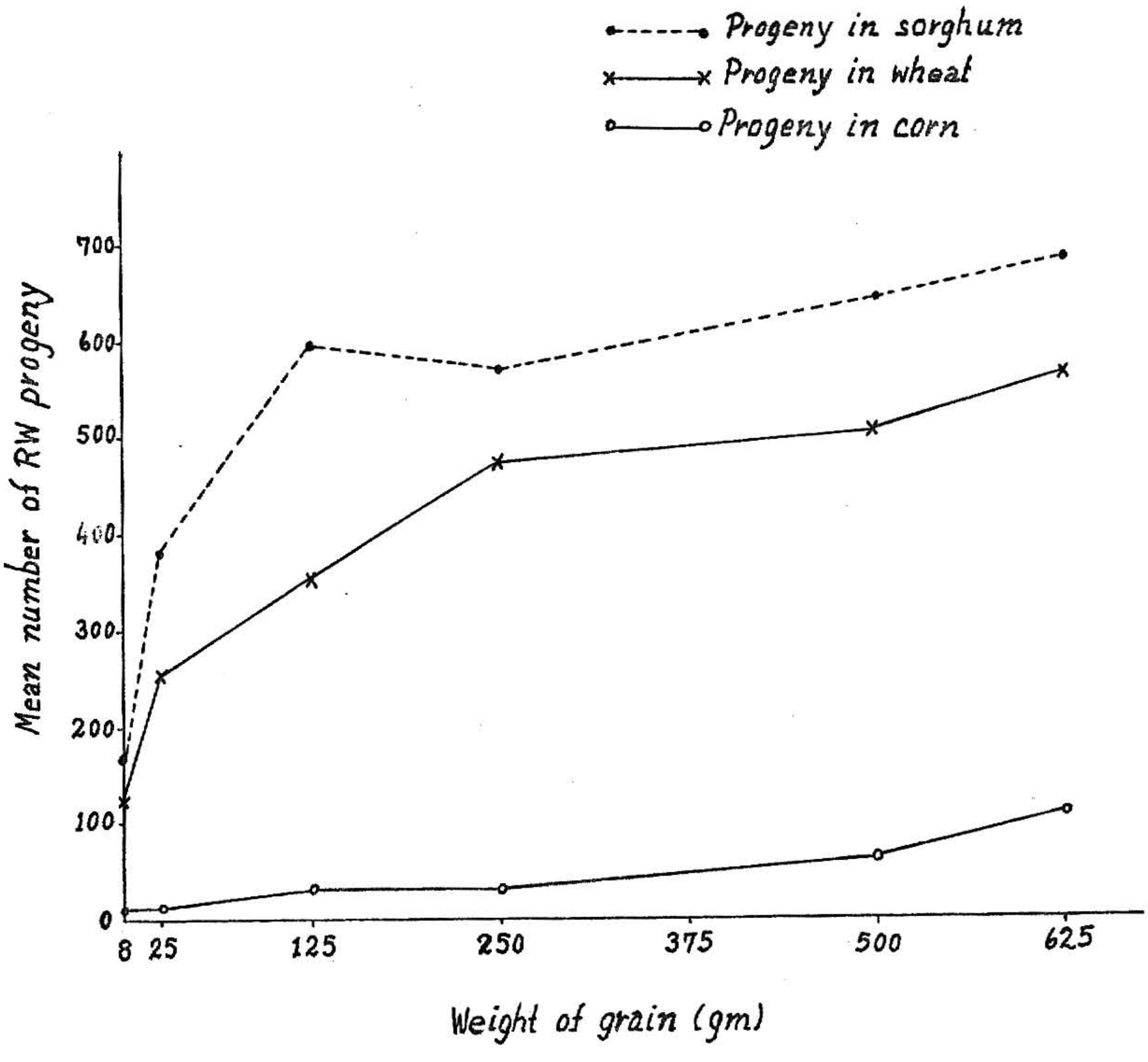
Sample size (gm)	Wheat			Sorghum			Corn		
	Approx. # kernels	# progeny		Approx. # kernels	# progeny		Approx.# kernels	# progeny	
		Mean	Range		Mean	Range		Mean	Range
8	302.4	120.8 c	99-139	307	167.8 c	127-212	25.85	11.2 d	2-21
25	945	295.4 b	169-359	959.4	381.4 b	333-457	80.8	13.8 d	6-25
125	4,725	353.8 b	259-544	4,797	596.4 a	510-726	404	28.2 c	20-39
250	9,451	472.8 a	366-666	9,594	568.4 a	371-749	808	27.4 c	18-44
500	18,900	503.2 a	245-684	19,188	642.6 a	540-762	1,616	61.4 b	45-90
625	23,625	565.4 a	380-768	23,985	684.2 a	564-760	2,020	109.0 a	83-146

Means followed by dissimilar letters are significantly different at the 5% level (within the same medium).

EXPLANATION OF PLATE VI

Mean numbers of rice weevil (RW) progeny produced in different quantities of wheat, sorghum, or corn of approximately 13.5% moisture content at 68±3% RH and 27±1°C. Fifty unsexed 7-to-14-day-old parent weevils/sample; 5 rep. sample; 6-day oviposition period.

Plate VI


Progeny in sorghum
Progeny in wheat
Progeny in corn
Mean number of RW progeny
700
600
500
400
300
200
100
0
8
25
125
250
375
500
625
Weight of grain (gm)

might not be large enough for maximum reproduction of 50 unsexed rice weevils. Personal observations revealed that one corn kernel could provide for the concurrent development of up to 4 rice weevils. The more eggs deposited in the same kernel, the higher the probability of internecine activity, thus less than maximum reproduction.

SEX RATIOS IN THE FOUR POPULATIONS REARED IN WHEAT, SORGHUM AND CORN

Materials and Methods

The adult weevils of all 4 populations were obtained from the stock cultures. Fifty active adults (for each of 5 replicates), 7-21 days old, were randomly-selected from each insect population reared in wheat, sorghum or corn. They were killed in 75% isopropyl alcohol. The total of 3,000 weevils were sexed by means of characteristics of the snout punctures and abdominal shape, according to Halstead (1963), Qureshi (1963) and Reddy (1951). In case of the very small weevils, which were difficult to sex using the external morphology, dissections were done to observe internal sex organs.

Results and Discussion

In all cases except one, the sex ratio did not differ significantly from 1:1. Rice weevils reared in corn had a sex ratio which differed significantly from unity (1:1) with more females than males (Table 10). In this case only small numbers of adults completed development in corn and only the active adults were picked up for sexing, perhaps not randomly because females may have been more active than males.

Table 10. Sex ratio in 4 populations of grain weevils reared in wheat, sorghum, or corn (5 replicates per population; 50 adult weevils each).

Culture medium	Species	Sex ratio (♂:♀) Rep. 1	Rep. 2	Rep. 3	Rep. 4	Rep. 5	Mean/rep.	Mean %/rep.
Wheat	MMW	26:24	23:27	20:30	21:29	24:26	28.8:27.2	45.6:54.4
	AMW	20:30	24:26	27:23	28:22	22:28	24.2:25.8	48.4:51.6
	RW	23:27	25:25	26:24	23:27	28:22	25.0:25.0	50.0:50.0
	GW	24:26	25:25	30:20	24:26	24:26	25.8:24.2	51.6:48.4
Sorghum	MMW	27:23	25:25	26:24	23:27	25:25	25.2:24.8	50.4:49.6
	AMW	28:22	24:26	20:30	27:23	29:21	25.6:24.4	51.2:48.8
	RW	25:25	22:28	27:23	25:25	25:25	24.8:25.2	49.6:50.4
	GW	23:27	23:27	24:26	27:23	26:24	24.6:25.4	49.2:50.8
Corn	MMW	25:25	25:25	23:27	24:26	31:19	25.6:24.4	51.2:48.8
	AMW	31:19	27:23	27:23	26:24	27:23	27.6:22.4	55.2:44.8
	RW	18:32	20:30	23:27	24:26	22:28	21.4:28.6	42.8:57.2*
	GW	25:25	24:26	22:28	25:25	24:26	24.0:26.0	48.0:52.0

*The only means (male:female) which differed significantly at the 5% level.

SUMMARY AND CONCLUSIONS

Infested samples handled every 48 hours to remove progeny yielded fewer progeny than similar samples which were not handled; however, differences were significant only for the Arkansas maize weevil (AMW) and the granary weevil (GW) (Table 1). The reduction was 16.2% for the AMW and 11.5% for the GW. Although these may not be considered drastic reductions, this phenomenon should be of concern in critical tests.

For all 4 populations, progeny production in all 3 grains was greater when parents were reared in wheat (Table 2). Effects of sorghum or corn as parent rearing media were variable. For the Mexican maize weevil (MMW) and AMW, progeny production in sorghum was greater than in wheat or in corn; for the rice weevil (RW) and the GW, wheat was the most favorable progeny rearing medium.

In comparing progeny production in wheat of the 4 populations, the RW produced significantly more progeny than the other populations when parents from all media were considered together (Table 3). The GW produced fewest progeny. Progeny production in sorghum was similar for the MMW, AMW, and RW, and significantly greater than for the GW. In corn, the progeny production of the 4 populations ranked from most to least: MMW, AMW, RW and GW; all differences were significant.

For all populations, parents reared in wheat produced progeny with the shortest developmental periods in all grains considered together (Table 4). For MMW and AMW developmental periods were intermediate for progeny of parents reared in corn. When considering parents from all media together, the developmental periods of progeny were shortest in sorghum for MMW and AMW, and in wheat for RW and GW. Results were variable in the other cases.

The mean developmental periods of progeny in wheat for each population when parents reared in all grains are considered together, rank from shortest to longest: AMW, RW, MMW and GW; all significantly different; in sorghum they ranked: MMW=AMW, RW and GW; in corn, MMW, AMW, RW and GW (Table 5). In most cases progeny developmental periods were shorter when parents were reared in wheat; in others, results were inconsistent.

The elytron lengths of progeny which developed in all 3 grains (considered together) were significantly larger for AMW and RW when parents were reared in wheat. Otherwise, parent rearing medium had no effect (Table 6). There was no correlation between size of parents and progeny as determined by elytron lengths. Progeny rearing medium was most responsible for differences in elytron length. For all insect populations, progeny from corn were significantly larger than those from wheat or sorghum. Elytron lengths of progeny of AMW and GW reared in wheat were significantly longer than in sorghum; for MMW and RW differences in these grains were nonsignificant.

Considering the size of parents in all media, there were no significant differences among MMW, AMW and GW (Table 7); RW were significantly smaller.

RW caused less weight loss in kernels of wheat and sorghum and were significantly lighter than other insects (Table 8). The AMW were significantly heavier than MMW in wheat, otherwise their weights were similar. Weight losses to kernels of all grains were similar for AMW and MMW. GW were heavier and produced greater weight losses in wheat kernels.

In 250-g samples of wheat and sorghum, 50 RW produced (statistically) as many progeny as in 500 and 625-g samples, but there was a tendency for progeny numbers to increase as grain quantity increased above 250 g. However, in corn the number of progeny increased as sample size increased (Table 9), which indicated that 250-g samples of corn used in previous experiments were too small for maximum reproduction of 50 parent weevils.

Sex ratio of adult weevils of 4 populations was 1:1 regardless of insect culture media, except RW reared in corn (Table 10).

ACKNOWLEDGMENTS

Sincere appreciation is expressed to Dr. Robert B. Mills, the major adviser, for his guidance, assistance, valuable suggestions and understanding. Grateful acknowledgment is also due to Dr. Gerald E. Wilde and Dr. Hobart P. Boles for their assistance and participation on the supervisory committee. Thanks are also due to Dr. Theodore L. Hopkins for providing special equipment, Dr. Kenneth E. Kemp for his assistance in statistical analysis, Mrs. Loretta Charlton for the laboratory assistance, and Mrs. Helyn Marshall for typing the thesis.

My special gratitude is given to Dr. Herbert C. Knutson, Head of the Department of Entomology, for his interest, encouragement, valuable advice, and for the recommendation of a partial graduate research assistantship.

LITERATURE CITED

Bailey, S. W. 1969. The effects of physical stress in the grain weevil, Sitophilus granarius. J. Stored Prod. Res. 5:311-324.

Birch, L. C. 1946. The influence of food on the size of two strains of Calandra oryzae L. Aus. J. Expt. Biol. and Med. Sci. 24:123-125.

Boles, H. P. (1975). The Arkansas laboratory strain of the maize weevil. Bull. Entomol. Soc. Amer. 21(32):165-168.

Coombs, C. W. 1972. The interpretation of experiments assessing the susceptibility of stored cereal to attack by Sitophilus spp. (Coleoptera, Curculionidae). J. Stored Prod. Res. 8:81-82.

Floyd, E. H., and L. D. Newsom. 1959. Biological studies of the rice weevil complex. Ann. Entomol. Soc. Amer. 52(6):687-695.

Golebiowska, Z. 1969. The feeding and fecundity of Sitophilus granarius L., Sitophilus oryzae L. and Rhyzopertha dominica F. in wheat grain. J. Stored Prod. Res. 5:143-155.

Halstead, D. G. H. 1963. External sex differences in stored products Coleoptera. Bull. Entomol. Res. 51(1):119-133.

Howe, R. W. 1952. The biology of the rice weevil, Calandra oryzae L. Ann. Appl. Biol. 39(2):168-180.

Howe, R. W., and B. D. Hole. 1967. The yield of cultures of Sitophilus granarius. J. Stored Prod. Res. 2:257-272.

Hunkapiller, P. D. and A. E. O'Donnell. 1967. A taxonomic separation of larvae of the genus Sitophilus by head capsule morphology (Coleoptera: Curculionidae). J. Kans. Entomol. Soc. 40(3):435-440.

Hurlock, E. T. 1965. Some observations on the loss in weight caused by Sitophilus granarius L. (Coleoptera, Curculionidae) to wheat under constant experimental conditions. J. Stored Prod. Res. 1:193-195.

Joffe, A., and B. Clarke. 1963. The effect of physical disturbance or turning of stored maize on the development of insect infestations. II. Laboratories studies with Sitophilus oryzae L. South Afr. J. Sci. 6:65-84.

Kiritani, K. 1965. Biological studies on the Sitophilus complex (Coleoptera: Curculionidae) in Japan. J. Stored Prod. Res. 1:169-176.

Lavadinho, A. M. P. 1974. Variation of adult body weight in Sitophilus granarius L. from laboratory cultures. J. Stored Prod. Res. 11:33-39.

LeCato, G. L. 1975. Species composition influencing insect population growth and weight loss of stored rice, wheat and corn. J. Kans. Entomol. Soc. 48(2):224-231.

Maceljski, M., and Z. Korunic. 1971. Additional contribution to the study of the morphology of the corn weevil (Sitophilus zeamais Motsch.). Zastita Bilja. 22(112-113):33-41.

McFarlane, J. A. 1968. The productivity and rate of development of Sitophilus oryzae L. (Coleoptera, Curculionidae) in various parts of Kenya. J. Stored Prod. Res. 4:31-51.

McLaurin, Jr., B. F., and A. E. R. Downe. 1966. Serological comparison of three species of grain infesting weevils (Curculionidae: Sitophilus). J. Kans. Entomol. Soc. 39(3):500-505.

Morrison, E. O. 1964. Effect of habitat disturbance on a rice weevil population (Sitophilus zeamais Mots.). The Texas J. Sci. XVI(1): 96-100.

Morrison, E. O. 1965. The effect of particle size of sorghum grain on development of the weevil Sitophilus zeamais. J. Econ. Entomol. 57(3):390-391.

Qureshi, A. H. 1963. Some sexual differences in the granary weevil, Sitophilus granarius (L.). The Canadian Entomol. 95:1117-1119.

Reddy, D. B. 1951. Determination of sex in adult rice and granary weevil (Coleoptera: Curculionidae). The Pan-Pacific Entomologist. XXVII(1):13-16.

Richards, O. W. 1944. The two strains of the rice weevil, Calandra oryzae L. (Coleoptera, Curculionidae). Trans. Royal Entomol. Soc. Lon. 94:187-200.

Sharifi, S., and R. B. Mills. 1971. Radiographic studies of Sitophilus zeamais Mots. in wheat kernel. J. Stored prod. Res. 7:195-206.

Singh, K., N. S. Agrawal, and G. K. Girish. 1972. Studies on the loss in weight caused by Sitophilus oryzae (Linn.) (Coleoptera, Curculionidae) to various high yielding varieties of wheat. Bull. Grain Tech. 10(4):271-275.

Soderstrom, E. L. and D. A. Wilbur. 1965. Variations in size and weight of three geographical populations of the rice weevil complex. J. Kans. Entomol. Soc. 38(1):1-9.

Soderstrom, E. L. and D. A. Wilbur. 1966. Biological variations in three geographical populations of the rice weevil complex. J. Kans. Entomol. Soc. 39(1):32-41.

Surtees, G. 1965. Effect of grain size on development of the weevil *Sitophilus granarius* (L.) (Coleoptera: Curculionidae). Proc. R. Entomol. Soc. Lond. (A). 40(1-3):38-40.

White, G. D. 1953. Weight loss in stored wheat caused by insect feeding. J. Econ. Entomol. 46(4):609-610.

A P P E N D I X

THE EFFECTS OF PARENT AND PROGENY REARING MEDIA ON THE OVIPOSITION AND THE DEVELOPMENT OF FOUR POPULATIONS OF GRAIN WEEVILS

Materials and Methods

Twelve 250-g samples of each grain, wheat, sorghum, and corn, were each placed in a wide-mouth mason jar with a 60-mesh screen lid and kelthane-treated filter paper on top for protection against mites. All grains were allowed to equilibrate in the rearing room at $27\pm1^{\circ}C$ and $68\pm3\%$ RH for 2 wk. For each population, 50 unsexed, 7 to 14-day-old parent weevils reared in wheat, sorghum or corn, were introduced, respectively, into each of 4 samples of wheat for 6 days oviposition, then all parents were removed. Four samples each of sorghum and corn were similarly infested. Each insect-infested sample was divided into 4 subsamples by using a Boehrner divider. Each subsample was stained for detecting of eggplugs by using acid fuchsin. Two hundred kernels of wheat or sorghum and 50 kernels of corn were randomly-selected from each stained subsample. Total number of kernels with eggplugs and total numbers of eggplugs were observed and recorded. Kernels with eggplugs from each of 4 subsamples were placed separately in a 48x48x48-mm plastic box with 40-mesh screen in the lid, and kept in the rearing room for the insect progeny development. Observations of adult progeny were made daily, beginning after 25 days from the beginning of parent oviposition, and the numbers of emerged adult progeny were recorded and removed daily. This experiment was ceased after 12 wk.

Results and Discussion

Mean numbers of kernels with eggplugs, mean numbers of eggplugs, mean numbers of progeny and the mean percent of progeny survival are shown in Table 1-4.

For MMW, the oviposition in wheat was greatest by parents reared in corn, and the mean percent of progeny survival (egg to adult) was highest when parents were reared in wheat. Numbers of eggs deposited and mean percent of survival of eggs to adults in sorghum by parents from all three grains were similar. In corn, MMW parents reared in corn oviposited more whereas parents reared in wheat oviposited at an intermediate rate and parents reared in sorghum the least. The mean percent of survival in corn was greater when parents were reared in sorghum; results obtained for parents reared in wheat and corn were similar (Table 1).

AMW oviposition in wheat and sorghum was greatest by parents reared in wheat, and the mean percent survival (egg to adult) was greatest for parents reared in sorghum. Parents reared in corn oviposited the greatest numbers of eggs in corn; the highest mean percent egg-to-adult survival was for parents reared in sorghum (Table 2).

Oviposition of RW in wheat was greater by parents reared in wheat or sorghum; the mean percent egg-to-adult survival was similar for parents reared in all 3 grains. In sorghum, the numbers of eggs deposited and the mean percent survival were similar for parents reared in all 3 grains. Parents reared in wheat or corn deposited more eggs in corn than those parents reared in sorghum and the mean percent egg-to-adult survival was higher when parents were reared in sorghum than when reared in wheat or corn (Table 3).

The GW parents reared in corn deposited the greatest number of eggs in wheat, but the mean percent egg-to-adult survival was lowest. The rates of oviposition in sorghum by parents reared in all 3 grains were similar and the mean percent egg-to-adult survival ranked from high to low for parents reared in sorghum, corn and wheat, respectively. In corn, oviposition ranked from high to low for parents reared in corn, wheat and sorghum, respectively. The mean percent egg-to-adult survival ranked from high to low for parents reared in wheat, sorghum and corn, respectively.

For each population these results were estimated from 4 subsamples taken from a 250-g sample of grain that was originally infested by 50 parent weevils. Statistical analysis was not done, since all observations for each insect (4 subsamples) came from one sample.

Table 1. Effects of parent rearing medium on MMW oviposition in wheat, sorghum, or corn; 4 replicates, 200 kernels/rep. (sorghum and wheat), 50/rep. (corn).

Parent rearing medium	# Kernels with eggplugs			Mean total # eggplugs	Mean # progeny	Mean % of survival
	Mean	Mean %	Range			
			Oviposition in wheat			
Wheat	9.5	4.75	8-12	9.75	8.0	82.05
Sorghum	7.0	3.5	7-8	7.75	4.0	51.61
Corn	6.75	8.12	21-23	18.0	13.25	73.61
			Oviposition in sorghum			
Wheat	7.75	3.88	6-9	8.75	6.75	77.14
Sorghum	7.25	3.62	5-10	8.5	6.62	77.71
Corn	6.75	3-37	4-8	7.25	5.5	75.86
			Oviposition in corn			
Wheat	22.25	44.5	13-18	39.5	18.25	46.2
Sorghum	6.75	13.5	3-11	8.75	5.5	62.86
Corn	29.25	58.5	26-32	74.5	38.0	51.01

Table 2. Effects of parent rearing medium on AMW oviposition in wheat, sorghum or corn; 4 replicates, 200 kernels/rep. (wheat and sorghum), 50/rep. (corn).

Parent rearing medium	# Kernels with eggplugs			Mean total # eggplugs	Mean # progeny	Mean % of survival
	Mean	Mean %	Range			
			Oviposition in wheat			
Wheat	10.25	5.12	7-13	10.75	7.0	65.11
Sorghum	6.5	3.25	4-8	6.5	4.75	73.07
Corn	6.0	3.0	5-8	7.0	3.50	50.0
			Oviposition in sorghum			
Wheat	12.75	6.75	11-16	16.0	10.0	62.5
Sorghum	8.75	4.37	5-10	9.5	8.0	84.21
Corn	5.75	2.87	4-10	8.25	5.0	60.6
			Oviposition in corn			
Wheat	16.0	31.5	12-18	22.0	14.0	63.63
Sorghum	7.25	14.5	6-9	7.0	6.0	85.71
Corn	15.25	30.5	14-17	31.5	14.75	46.81

Table 3. Effects of parent rearing medium on RW oviposition in wheat, sorghum, or corn; 4 replicates, 200 kernels each (wheat and sorghum), 50 kernels each (corn).

Parent rearing medium	# Kernels with eggplugs			Mean total # eggplugs	Mean # progeny	Mean % of survival
	Mean	Mean %	Range			
			Oviposition in wheat			
Wheat	11.0	5.5	9-14	12.25	9.75	79.59
Sorghum	7.75	3.87	7-10	7.75	6.75	87.09
Corn	15.5	7.75	14-18	17.0	9.75	57.35
			Oviposition in sorghum			
Wheat	9.5	4.75	6-11	10.5	7.75	73.8
Sorghum	6.0	3.0	5-7	8.0	5.5	68.75
Corn	9.75	4.87	9-11	11.75	8.25	70.21
			Oviposition in corn			
Wheat	17.75	35.5	16-21	27.75	15.0	54.05
Sorghum	8.75	17.5	8-10	11.5	7.25	63.04
Corn	13.25	26.5	11-16	26.25	11.0	41.9

Table 4. Effects of parent rearing medium on GW oviposition in wheat, sorghum or corn, 4 replicates, 200 kernels each (wheat and sorghum), 50 kernels each (corn).

Parent rearing medium	# Kernels with eggplugs Mean	Mean %	Range	Mean total # eggplugs	Mean # progeny	Mean % of survival
			Oviposition in wheat			
Wheat	6.0	3.0	4-7	6.5	4.25	65.38
Sorghum	6.5	3.25	6-9	6.75	4.67	69.25
Corn	10.0	4.5	8-12	10.5	5.75	54.76
			Oviposition in sorghum			
Wheat	3.75	1.87	3-5	4.25	2.25	52.94
Sorghum	4.0	2.0	2-6	4.0	2.75	68.75
Corn	4.5	2.25	11-17	4.75	3.0	63.15
			Oviposition in corn			
Wheat	12.75	25.5	10-15	18.75	10.0	55.33
Sorghum	7.0	14.0	3-14	10.0	4.0	40.00
Corn	13.0	26.0	3-6	28.75	5.0	17.39

EFFECTS OF CULTURE MEDIA ON THE BIOLOGY AND BEHAVIOUR OF FOUR POPULATIONS OF GRAIN WEEVILS (CURCULIONIDAE, *SITOPHILUS*)

by

AMPAI UNGSUNANTWIWAT

B. S., Kasetsart University
Bangkok, Thailand, 1970

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Entomology

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1976

Four populations of *Sitophilus* weevils were studied, including 2 maize weevil populations (*S. zeamais* Mots.), one from Arkansas (AMW); one from Mexico (MMW); one rice weevil population (*S. oryzae* L.) (RW); and one granary weevil population (*S. granarius* L.) (GW). All had been maintained in wheat in the Kansas State University Stored-Product Insects Laboratory for several years ($27 \pm 1^{\circ}C$ and $68 \pm 3\%$ RH). Wheat, sorghum and corn (13.5% moisture content) were used to determine effects of rearing media of both parents and progeny on the numbers of progeny developing, developmental periods, sizes of adults and effects of handling weevil-infested grain on numbers of progeny surviving. Weight loss of individual kernels of wheat, sorghum or corn caused by the development of single insects, and weevil weights, were determined. The effects of quantities of wheat, sorghum or corn on numbers of progeny of the rice weevil were determined. All experiments were conducted in a rearing room with $27 \pm 1^{\circ}C$ and $68 \pm 3\%$ RH.

Infested samples handled every 48 hr to remove progeny, yielded fewer progeny for all populations than similar samples which were not handled; however, differences were significant only for AMW and GW.

For all 4 populations, progeny production in all 3 grains was greater when parents were reared in wheat. Sorghum was the most favorable progeny rearing medium for MMW and AMW, and wheat for RW and GW. In comparing the 4 populations, GW produced significantly fewer progeny in all grains whereas the RW produced the most in wheat and MMW produced the most in corn, but differences among MMW, AMW and RW progeny production in sorghum were not significant.

Developmental periods for all populaltions were shortest when parents were reared in wheat. For MMW and AMW, developmental periods were intermediate for progeny of parents reared in corn. In sorghum, developmental periods were shortest for MMW and AMW, and in wheat were shortest for RW and GW. Comparing all populations, they ranked from shortest to longest in progeny developmental period: AMW, RW, MMW, and GW in wheat; MMW=AMW, RW and GW in sorghum; MMW, AMW, RW and GW in corn.

The elytron lengths of parents and progeny reared in all 3 grains were measured; there were no correlations between parent elytron length and progeny elytron length. The AMW and RW progeny elytron lengths were significantly longer when parents were reared in wheat, otherwise parent rearing media had no effects. Progeny rearing medium was most responsible for differences in elytron lengths. For all populations, progeny from corn were significantly larger than those from wheat or sorghum. Comparison of all parent elytron lengths in all media, revealed no significant differences among MMW, AMW and GW, whereas RW were significantly smaller than the other three.

RW caused less weight loss in kernels of wheat and sorghum, and were significantly lighter than the other insects. The AMW were significantly heavier than MMW in wheat, otherwise their weights were similar. Weight losses to kernels of all grains were similar for AMW and MMW. GW were heavier and produced greater weight losses in wheat kernels.

In 250-g samples of wheat and sorghum, 50 unsexed RW produced statistically as many progeny as in 500 and 625-g samples, but there was a tendency for progeny numbers to increase as grain quantity increased above 250 g. In corn, the number of progeny increased as sample size increased, which indicated that the 250-g sample of corn was inadequate for maximum reproduction of 50 parent weevils.

Sex ratio was 1:1 for all 4 populations regardless of culture media, except RW reared in corn.