SUCCESS OF DEVELOPMENT AND EXTENT OF FEEDING DAMAGE OF STORED-PRODUCT INSECTS IN CULTIVARS OF SORGHUM AND MILLET

by

NOUR AWAD ELKARIM SINADA

B.Sc. (1982) College of Biological Science
University of Khartoum
Khartoum, Sudan

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Approved by:

Major Professor

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INTRODUCTION

Sorghum and millet are among the major food grains in most African countries, and are very important in Sudan.

Many of the primary and secondary stored-product Coleopterans and Lepidopterans are common pests on sorghum and millet. The grain varieties vary in their susceptibility to insect attack, perhaps based on the hardness of kernels, with the hard varieties being more resistant (Russell and Rink, 1965; Davey, 1965), or on size of the kernels, with the smaller kernels being more resistant for most insects (Doggett, 1957; Seifelnasr, 1984). Damage in the grain due to harvesting and handling, moisture content of the grain, and smoothness of the kernels may contribute to the damage and losses caused by stored-product insects.

Quantitative estimates of losses can be used to determine whether control measures are needed and what types. The ability to estimate losses would be particularly important in developing countries where food is in short supply and losses are reported to be high. This would enable the governments and international aid agencies to better evaluate storage situations and improve programs for grain preservation.

The objectives of this study are to determine the damage and grain weight loss caused during development of four species of stored-product insects in two cultivars of sorghum and two cultivars of millet.

GENERAL LITERATURE REVIEW

Storage losses during World War II, which were critical because of food shortages, brought about increased study of storage insects that has continued to the present, but there still is little accurate information on losses (Tyagi and Girish, 1975). Adams (1977) in a review of the literature dealing with losses in stored cereals and pulses, reported that many authors have not adequately defined loss. That makes it difficult, especially with field estimates, to compare loss assessments by different investigators, even within the same locality. Therefore, although commonly agreed that losses caused by stored-grain insects are considerable, accurate estimates of their magnitude are lacking.

Major Insect Pests of Sorghum and Millet

Sorghum and millet are the major food grains in most African countries (De Las Casas,1983). They are cereals of essentially warm, dry areas and are mostly consumed locally. Resistance of stored sorghum cultivars [*Sorghum bicolor* (L.) Moench] to insect attack has received attention from many workers, but little work has been done on resistance of pearl millet (*Pennisetum americanum* (L.) Leeke).

For both millet and sorghum, Sitophilus oryzae (L.) was reported as the major pest and found in about 95% of the producing areas (Champ,1981). Calandra oryzae L. (Sitophilus oryzae) is the most common insect pest of jowar (Sorghum vulgare) in India (Venkatrao et al.,1958). Giles (1965) found that Sitophilus oryzae is a major pest of stored sorghum in Northern Nigeria. He found that it also infests millet, maize and wheat.

Rhyzopertha dominica (F.) is the second most damaging pest of sorghum and millet (Champ,1981). Champ also reported that, Ephestia cautella (Walker), Corcyra cephalonica (Staint.), Trogoderma granarium (Everts) and Oryzaephilus surinamensis (L.) are serious pests of sorghum in hot areas, and Sitotroga cerealella (Olivier) is a major pest of unthreshed sorghum. Johnston and Sorenson (1952) found that the most common insect pests in stored sorghum grain in South Texas were the rice weevil, lesser grain borer, red flour beetle, and Angoumois grain moth.

Sharma et al. (1977) studied the host preference of the rice moth, C. cephalonica and the almond moth, E. cautella on maize, wheat, sorghum, rice and groundnut. Sorghum was the most suitable host based on higher per cent larval survival to pupa and adult, higher pupal weights and significantly faster development.

Factors Affecting Resistance in Sorghum and Millet

There are numerous physical and chemical factors, or combinations of these, that render grain resistant or susceptible to one stored-grain insect or another. Investigators have suggested that factors such as texture or toughness of pericarp, hardness, kernel size, kernel soundness and chemical factors might influence resistance of grain (Mills, 1972). Seifelnasr and Mills (1985) studied the resistance of 37 pearl millet cultivars to the Angoumois grain moth, rice weevil and lesser grain borer. The reactions of the cultivars to the rice weevil and Angoumois grain moth were more similar than when either was compared with the lesser grain borer. Also, no single cultivar was ranked most resistant (or susceptible) to all three insect species.

Kernel hardness of sorghum and resistance to insect damage has been related. Doggett (1957) and Russell and Rink (1965) found that harder grain varieties were least attractive to weevils for oviposition. Davey (1965) placed newly-emerged rice weevil males singly on 2 sorghum kernels of either mealy or vitreous varieties in separate tubes. Adults on mealy varieties consumed more per day than those on vitreous varieties, about 0.2 and 0.15 mg per mg body-weight of weevil, respectively. Doraiswamy et al. (1976)

found a negative correlation between seed hardness and susceptibility to rice weevils, and fewer adults emerged from harder varieties.

Size of kernels has been associated with susceptibility/resistance. Doggett (1957) found that smaller sorghum grains received fewer weevil egg plugs. Seifelnasr and Mills (1985) reported that millet seed size varied inversely with resistance to rice weevils and Angoumois grain moth, however, it was less related to resistance to lesser grain borer.

Damage to stored grains, due to mechanical harvesting and handling, render grains more susceptible to infestation by post-harvest insects, especially secondary insects like flour beetles, which probably cannot attack perfectly sound grains. Sinha (1972) tested the infestability of millet, oilseeds and clover by *Tribolium castaneum*, *T. confusum*, *Oryzaephilus mercator*, and *Cryptolestes ferrugineus*. Crushed seeds of millet, clover and oilseeds were considerably more susceptible than whole seeds to infestation by all species of insects. Williams and Mills (1980) found that abrading the pericarp of resistant sorghum cultivars rendered them as susceptible as abraded susceptible cultivars to the attack by rice weevils.

Weight Loss in Stored Grains Due to Insect Feeding

Different insects cause different weight losses in grains. The same species might cause different weight losses in different grains. Ungsunantwiwat (1976) compared weight losses caused by feeding of rice weevil, maize weevil, and granary weevil during development from hatching to adult emergence. The granary weevil, the largest, caused the greatest over-all average weight loss per kernel per insect (15.03 mg) in sorghum and wheat. The rice weevil, the smallest, caused significantly less average weight loss (10.30 mg) in these grains than the other species. Even the site of feeding varies with the insect species, e.g., germ, endosperm, or both.

Rice weevil, Sitophilus oryzae, like other weevils, is very well adapted to feed on sound grains because it can chew into the grain. The rice weevil female lays a single egg in a hole chewed into the kernel, then plugs the hole with a gelatinous secretion from the ovipositor. The hatched larva feeds internally, pupates, and the adult chews its way out of the kernel. Therefore, the kernel weight loss is due to feeding of both larva and the emerging adult. Singh et al. (1972) found that the average kernel weight loss caused by single S. oryzae larvae during development differed among wheat varieties. The mean weight of adults produced ranged from 2.1 to 2.4 mg.

The lesser grain borer, Rhyzopertha dominica is a very serious pest in stored grains; most larvae live inside the kernels, but they can live outside. In addition to damage caused to grain due to larval and adult feeding, the lesser grain borer produces much dust that contaminates the grain. It also produces a distinct and unpleasant odour. Rao and Wilbur (1972) found that 20 days of feeding by newly-hatched lesser grain borer larvae on wheat kernels resulted in 9.5% weight loss per kernel, while one week of adult feeding resulted in 19.4% weight loss per kernel.

Kamel and Zewar (1973) found that when millet seeds had the same percentage infestation of S. oryzae or R. dominica, the consumption of millet was similar for the two species. Campbell and Sinha (1976) showed that weight loss of single kernels of wheat due to feeding of single larvae was greatest by S. granarius (60%), followed by R. dominica (17%), and C. ferrugineus (Stephens) (4%). However, kernel weight loss and frass production by adults were greatest for R. dominica than for the other two insects. Morallo-Rejesus and Javier (1980) measured the percent weight loss and percent reduction in germination caused by Sitophilus spp. and R. dominica in four stored cereals. The weevils caused the most damage in corn and sorghum and the least in rice, while the lesser grain borer caused the greatest damage in sorghum followed by milled rice and rough rice, and the lowest in corn.

The rice moth, Corcyra cephalonica and almond moth, Cadra cautella are both germ feeders. Larvae of both insects, as well as larvae of other stored-product moths, damage stored cereals directly by reducing their weight and viability, and indirectly by contaminating with frass, their bodies, and large quantities of silk. Burges and Haskins (1965) reported Cadra cautella as a pest of stored cereals, nuts, and dried fruit. Mookherjee and Khanna (1971) found that one almond moth larva is capable of feeding on and destroying the germs of an average 12.28 wheat seeds as it completes development.

Pingale et al. (1954) in a study of the effect of infestation of 100 adults of Calandra (Sitophilus) oryzae or 100 Ephestia (Cadra) cautella infestation on 70-lb. lots of soft wheat, found that the weevils and their progeny caused the higher reduction in grain weight (11.25% after three months), while the almond moths and their progeny caused 1.73% weight loss. However, because they feed mostly on the germ, the percentage of kernels damaged at the end of the three-month period was 22.49 for the moth compared to 21.71 for the weevils.

Some studies have been done on success of feeding and development of moth larvae on kernels of grain. Chaudhary and Bhattacharya (1976) studied the developmental behaviour of Ephestia (Cadra) cautella on several food commodities including wheat, maize and bajra (sorghum). When 15 0- to 24-hour-old larvae were placed with 20 grams of either whole grain, whole flour, whole flour + 5% yeast, or whole autoclaved flour + 5% yeast of each grain, they found that the whole flour + 5% yeast had the highest percent adult emergence for wheat, maize and sorghum, followed by whole flour, whole autoclaved flour + 5% yeast, and the lowest percentage was in whole grain. Dobie (1978) studied the behaviour of Ephestia (Cadra) cautella in infesting previously infested carob pods (field infestation) by Ectomyelois ceratoniae and previously uninfested carob pods. He found that when newly-hatched C. cautella larvae were given a choice between the two kinds of pods, significantly more of them selected the previouly infested pods. Also, larvae of E. cautella successfully developed upon sections of the pods with previous infestation but failed almost completely to develop upon the pods without previous infestation.

GENERAL MATERIALS AND METHODS

Test Insects

The insects used in the experiments included rice weevil (RW), *Sitophilus oryzae* (L.); lesser grain borer (LGB), *Rhyzopertha dominica* (F.); rice moth (RM), *Corcyra cephalonica* (Staint.); and almond moth (AM), *Cadra cautella* (Walker), which were obtained from stock cultures maintained in the Stored-Product Insects Laboratory, Department of Entomology, Kansas State University. All were from cultures that had been maintained for many generations, the RW and LGB on whole wheat kernels, and RM and AM on a special medium [poultry laying mash (4 parts), rolled oats (2.5 parts), and glycerine (1 part)].

Test Cultivars of Sorghum and Millet

The sorghum [*Sorghum bicolor* (L.) Moench] cultivars used were Dekalb 32 and Shallu MP10 grown in 1984. The pearl millet [*Pennisetum americanum* (L.) Leeke] cultivars used included a millet hybrid (2090 X 7024) and Casady millet hybrid (4039) grown in 1979. All sorghum and millet cultivars were provided by the Department of Agronomy, Kansas State University. The kernels of the two sorghum cultivars were similar in size. The Dekalb 32 cultivar was obviously not pure because there were both brown and white kernels. Only white kernels were used for this study to eliminate the possible influence of tannin. The kernels of Shallu MP10 were white. The kernels of both sorghums were tested for relative hardness by measuring the relative penetration of a pointed hard metal rod (2.5 mm diam.) that left a diamond-shaped impression in the kernel. The rod was weighted with 2 kg and rested on the kernel for 20 sec. Relative hardness was determined by measuring one of the diagonals of the impression. Statistical analysis indicated no difference between the means, although Shallu MP10 had shorter diagonal (0.53 mm) than Dekalb 32 (0.55 mm). Seifelnasr (1984) had tested the kernels of the two millets and described the kernels of millet 2090 X 7024 as large and soft and those of millet 4039 as small and hard. In addition, transverse sections of kernels from all four cultivars were photographed using a polaroid film type 667. Shallu MP10 was found to have more corneous (vitreous) endosperm than Dekalb 32, and millet 4039 had more corneous endosperm than millet 2090 X 7024 (Plate 1). All cultivars were placed in a freezer for at least two weeks to destroy any possible infestation and then kept in a cold room (5^{o}C) until used.

Maintenance of Insect cultures

Insect cultures were maintained in a rearing room at 27$\pm$1^{o}C, 67$\pm$3% RH and 14L:10D photoperiod. Each species was reared in sorghum and millet so they would become accustomed to the types of grain in which they would be tested.

RW and LGB were maintained in one-pint, wide-mouth Mason jars half-filled with sorghum or millet grain. The jars were covered with caps containing 60-mesh brass wire screen and 9-cm Fisher Brand filter paper inserts. They were placed on inverted petri dishes in a metal tray containing a thin layer of paraffin oil. The filter paper inserts and the paraffin oil were to protect the cultures from possible infestation or contamination by other insects or mites.

At 2-week intervals approximately 200 one- to two-week-old, unsexed, adult RW or LGB were placed in each of two culture jars for each medium. After a two-week ovipositional period, the parent adult RW and LGB were removed using #10 and #12 sieves for sorghum and millet, respectively, and then discarded. The grains containing eggs and larvae were kept in the rearing room for 6 more weeks, at which time the emerging adults were used as parents for new cultures, and the old cultures were then discarded.

Seven-to-14-day-old RW used in all experiments were obtained from these cultures by removing and discarding all emerged adults from the 6-week old cultures, then keeping the cultures for one week for additional adult emergence. These 0-to 7-day-old adults were placed on fresh sorghum or millet for 7 more days then used, at an age of 7-14 days.

For LGB, sorghum or millet in which adults had been for 7 days oviposition was screened using #50 and #80 sieves. #50 sieves collected the grain and the insects and #80 sieves collected the eggs and some newly-hatched larvae. The grain and the insects were retained for culture development, the young larvae were destroyed and the eggs were spread in 2-3 petri dishes, covered, labelled and incubated in the rearing room. The eggs were checked daily and if the number of first instar larvae was less than the required number, they were eliminated and the eggs were checked the next day. When a sufficient number of 0- to 24-hour-old first instar larvae were available they were used in tests.

The RM and AM cultures were maintained in one-quart, wide-mouth Mason jars half-filled with partially ground sorghum or millet grain. The jars had lids similar to those for RW and LGB. Gallon jars one-third filled with either medium were used for rearing RM, since RM were found to produce better under conditions of abundant space and food supply (Teotia and Singh, 1977). A 1-in.-wide coil of corrugated cardboard paper containing RM or AM pupae was placed in each of the four jars of their respective media. The emerging adults were left to mate and lay eggs. The pupation coils were removed after 2 weeks and new empty coils were placed in the grain for pupation of the progeny.

As soon as emergence began in each jar the coils were removed and placed in new cultures for further culture development; new coils were placed in the old jars to collect more pupae. Sometimes when large numbers of adult moths were available, some were placed in oviposition jars and the eggs collected were used to start new cultures, rather than using pupae in coils.

To obtain newly-hatched larvae of RM and AM, eggs were first collected in oviposition jars. Twenty to 40 newly-emerged, unsexed RM or AM adults were placed in a one-pint, wide-mouth Mason jar. The jar was covered with a cap containing 20-mesh brass wire screen. The covered jar was placed up-side-down on the bottom of a petri dish, and 1-in. masking tape was used to hold the dish to the jar. The newly-laid eggs passed through the screen into the petri dish. The oviposition jars were kept in the rearing room for 4 days for RM (incubation period is longer) and 3 days for AM. The eggs were used either to develop new cultures or for experiments.

For all experiments eggs were placed in flat-bottom glass vials, which were closed with cork stoppers and labelled, then placed in the rearing room. Each vial contained from 60 to 80 eggs. The vials were checked daily for hatched larvae. If the number was less than needed, the larvae were removed and destroyed, and the remaining eggs were incubated for another day. When the required number of 0- to 24-hour-old larvae were obtained in one day, they were used in the experiments.

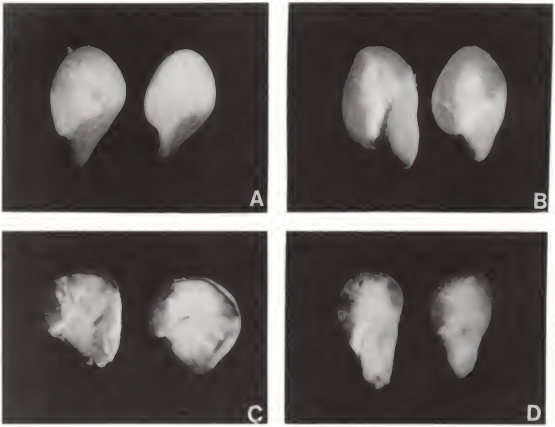
Plate 1. Transverse sections of kernels showing proportions of corneous (vitreous) and floury (starchy) endosperm (60 X).

A. Dekalb 32 sorghum.

B. Shallu MP10 sorghum.

C. Millet hybrid 2090 X 7024.

D. Casady millet hybrid 4039.


A
B
C
D

PART I

SITOPHILUS ORYZAE (L.) AND *RHYZOPERTHA DOMINICA* (F.) DEVELOPMENT IN SORGHUM AND MILLET: DEVELOPMENTAL PERIOD, BODY WEIGHT, AND WEIGHT LOSS CAUSED TO INDIVIDUAL KERNELS.

Introduction

The damage and reduction in weight in single grain kernels caused by the feeding and development of internal feeding insects has been studied by several investigators. Most of the work has been devoted to wheat, corn or sorghum.

The extent of damage, type of damage, kernel weight loss, developmental period and size of emerged insect are greatly related to the behaviour of different species of insects, the feeding stage(s), and the size and kind of kernels. Campbell and Sinha (1976) found that weight loss to single kernels of wheat due to the feeding of single larvae was greatest for *Sitophilus granarius* (60%) followed by *Rhyzopertha dominica* (17%) and *Cryptolestes ferrugineus* (4%). The kernel weight loss and frass production by adults was greater for *R. dominica* than for the other two insects.

Morrison (1964) studied the effect of particle size of sorghum grain on the development of maize weevils by placing 10 pairs of maize weevils with 100 g of sorghum grains for 35 days. The largest mean number of weevil progeny emerged from whole kernels (21.6), next from halved kernels (14.8) and the least from coarsely-ground sorghum (1.2). Hardness of sorghum kernels has been found to be negatively correlated to the susceptibility to rice weevils (Doggett, 1957; Russell and Rink, 1965; Doraiswamy et al., 1976).

This study was to compare the effect of kernel vitreousness of two sorghum cultivars and kernel size and hardness of two millet cultivars on the developmental periods and size of emerged rice weevils and lesser grain borers, and to compare the amount of weight loss caused by single insects feeding on single kernels.

Materials and Methods

The rice weevil (RW), *Sitophilus oryzae* (L.) and the lesser grain borer (LGB), *Rhyzopertha dominica* (F.) were from stock cultures that had been maintained for several years on whole wheat. Each species was then cultured in sorghum and millet for at least six generations to be acclimated to those types of grain before using in the experiments. All cultures were kept in a rearing room at $27\pm1^{o}C$, $67\pm3\%$ RH and 14L:10D photoperiod. The sorghum and millet cultivars were provided by Department of Agronomy, Kansas State University. The millet cultivars used in this test were hybrids 2090 X 7024 (large and soft kernels) and 4039 (small and hard kernels), and the sorghums were Shallu MP10 (hard kernels) and Dekalb 32 (soft kernels). The grain to be tested was equilibrated in the rearing room for at least 2 weeks.

Rice Weevil

Using a binocular microscope and examining each kernel individually, 200 uniform and undamaged kernels were selected from each cultivar of sorghum. Twelve female and 6 male, 7-14 day-old rice weevils from sorghum cultures were placed with each sorghum sample in a small, 60-ml glass jar with pin holes in its plastic lid for ventilation. The parent weevils were removed after three days. The 200 kernels were then checked inside the rearing room to prevent moisture content changes, and 10 kernels, each with one weevil eggplug, were selected and weighed using a CAHN 28 Automatic Electrobalance, and placed in singly equilibrated #1 gelatin capsules until adult progeny emergence. From the time that first emergence was expected, capsules were checked daily. The date of emergence was recorded, and each weevil was weighed. The kernels were brushed off externally and as much internal frass as possible was shaken out through the emergence holes. They were then kept in the rearing room for 2 weeks so that the kernels could equilibrate free of the insects inside, then weighed. It was expected that the moisture content of the damaged kernels would equilibrate to the same level as when they were originally weighed. The same test was done for millet cultivars using parent weevils from millet cultures. Four replicates were done for each grain.

Lesser Grain Borer

Using a binocular microscope inside the rearing room, 24 uniform, undamaged, and equilibrated kernels were selected from each variety of sorghum. The pericarp of each kernel was punctured with an insect pin at the boundary separating the germ and endosperm to assure an entry site for the larva. The kernels were weighed using a CAHN 28 Automatic Electrobalance, then placed individually in equilibrated #1 capsules. Lesser grain borer eggs were collected from sorghum cultures using 50-mesh and 80-mesh sieves. The 50-mesh sieve collected grains and insects and the 80-mesh sieve collected eggs but permitted a few newly-hatched larvae and the fine dust to pass through. The larvae were destroyed and the eggs were then scattered on the bottoms of 2-3 petri dishes and incubated in the rearing room. The eggs were observed daily for hatching, after which, using a fine camel hair brush, a newly-hatched larva was transferred to each capsule containing a damaged kernel. Daily observations for adult emergence were started 21 days after infestation. Emerged adults were weighed and the kernels were brushed off and frass inside the kernels was shaken out through the emergence holes, as much possible. They were then kept in the rearing room for 2 weeks to be equilibrated to eliminate any moisture effects the larvae might have had. The kernels were then weighed. The same test was done for millet cultivars using LGB reared in millet, and repeated four times for each grain.

For each test the actual and percent losses in kernel weight, the developmental periods and weights of emerged insects were statistically analyzed (ANOVA).

Results and Discussion

Kernel weight loss

The mean single kernel weight losses caused by individual lesser grain borers (LGB) in Shallu MP10 (6.85 mg) were not significantly different from those caused in Dekalb 32 (7.38 mg); the same was true for rice weevil (RW) (10.10 mg in Shallu and 10.41 mg in Dekalb) (Table 1). The mean actual kernel weight loss was significantly less in millet 4039 (5.16 mg and 6.50 mg) than in millet 2090 X 7024 (6.03 mg and 8.28 mg) for both LGB and RW, respectively, and also kernel weight loss to millet was significantly less than to sorghum for each insect. Since millet kernels are smaller than sorghum kernels the percent kernel weight losses are greater in millet.

The Shallu and Dekalb kernels were about similar in weight, which may explain the similar kernel weight loss due to RW and LGB feeding. The number of weevils that successfully completed development in Shallu (24 of 40) was greater than in Dekalb (16 of 40). Davey (1965) found that newly-emerged rice weevil males placed with mealy (floury) sorghum kernels consumed more endosperm than those placed on vitreous (corneous) kernels; 0.20 and 0.15 mg/day/mg body weight, respectively. In the present experiment the amount of floury endosperm in sorghum kernels seemed to have no significant effect on the amount of food each LGB or RW consumed, although, slightly more weight loss was caused in Dekalb kernels which have more floury endosperm than in Shallu.

In millet RW or LGB feeding caused significantly less mean weight loss in the smaller, harder kernels of 4039 than in 2090 X 7024. Seifelnasr and Mills (1985) stated that the size of millet kernels varied inversely with the resistance to rice weevils (progeny production) and Angoumois grain moths (success of development) but it was less related to resistance to lesser grain borer. However, this test was no-choice, in contrast to their free-choice tests.

Weight and developmental period of emerged insect

The mean weights of emerged RW were similar for Dekalb (1.73 mg) and Shallu (1.73 mg) but the mean developmental period was significantly longer in the latter than the former (36.7 and 37.9 days, respectively) (Table 2). The millet 2090 X 7024, having larger, softer kernels, produced significantly larger RW (1.43 mg) than the millet 4039 (1.01 mg), while the mean developmental period was shorter in the former (33.9 days vs. 35.3 days). The RW weights in 2090 X 7024 and 4039 and developmental periods in 2090 X 7024 were significantly different from those in sorghum, while the developmental period in 4039 was not significantly different from that in Dekalb.

Weights of emerged RW were directly related to the amount of food consumed by each insect. The mean kernel weight loss and insect weight ranked highest in sorghum cultivars followed by millet 2090 X 7024 and lowest for millet 4039. However, the mean devlopmental periods were not directly related to the kernel weight losses or to the insect weights, but may be related to the amount of floury endosperm in the kernels for sorghum and to the size and hardness of the kernels for millet. The developmental periods ranked from longest in Shallu, Dekalb, millet 4039, and shortest in millet 2090 X 7024.

Also for LGB, Shallu along with millet 2090 X 7024 produced the heavest adults (1.24 mg) (Table 2). Dekalb ranked third in mean weight of insects (1.18 mg), although, the insects caused the greatest kernel weight loss, while LGB emerged from millet 4039 had the smallest average weight (1.10 mg). The LGB had quite uniform developmental periods in all sorghum and millet cultivars; there were no significant differences among them.

These experiments indicated that although RW and LGB caused greater percent kernel weight losses in millet than in sorghum, actual weight losses were greater in sorghum than in millet. RW from sorghum were heavier than those from millet, but LGB weights were variable. Developmental periods of LGB were not influenced by type of grain or cultivar, while they were variable for the RW.

Table 1. Mean kernel (sorghum and millet) weight losses caused during development and emergence of individual rice weevils and lesser grain borers.

Variety	No. insects emerged	Kernel weight (mg)	Kernel weight loss	
			mg.	%
		Rice Weevil		
Dekalb 32	16	24.14	10.41 a	44.41 c
Shallu MP10	24	26.01	10.10 a	38.93 c
Millet 2090 X 7024	30	14.75	8.28 b	56.87 b
Millet 4039	21	9.60	6.50 c	68.24 a
		(4 replicates of 10 infested kernels each)		
		Lesser Grain Borer		
Dekalb 32	60	27.19	7.38 a	27.79 c
Shallu MP10	54	27.50	6.85 a	24.99 c
Millet 2090 X 7024	55	15.86	6.03 b	39.04 b
Millet 4039	55	7.92	5.16 c	66.11 a
		(4 replicates of 20 kernels each)		

Means for the same insect followed by the same letter are not significantly different (Alpha = 0.05), as determined by Tukey's Studentized Range Test.

Table 2. Mean weight and developmental periods of rice weevils (days ± 2) and lesser grain borers (days ± 1) emerged from single sorghum or millet kernels.

Variety	No. insects emerged	Weight (mg)	Devel. period
	Rice Weevil		
Dekalb 32	16	1.73 a	36.7 ab
Shallu MP10	24	1.73 a	37.9 a
Millet 2090 X 7024	30	1.43 b	33.9 b
Millet 4039	21	1.01 c	35.3 ab
	(4 replicates of 10 infested kernels each)		
	Lesser Grain Borer		
Dekalb 32	60	1.18 ab	37.8 a
Shallu MP10	54	1.24 a	38.9 a
Millet 2090 X 7024	55	1.24 a	38.2 a
Millet 4039	55	1.10 b	36.8 a
	(4 replicates of 20 kernels each)		

Means in the same column for the same insect followed by the same letter are not significantly different (Alpha = 0.05), as determined by Tukey's Studentized Range Test.

PART II

EFFECT OF REARING MEDIUM OF PARENTS ON RELATIVE RESISTANCE/SUSCEPTIBILITY OF FOUR SORGHUM AND MILLET CULTIVARS TO *SITOPHILUS ORYZAE* (L.)

Introduction

Resistance of different cereal grains to stored-product insects has been related to several factors (Mills, 1972). Davey (1965) reported that hardness of sorghum kernels is the most important factor responsible for resistance to rice weevil attack. Maneechoti (1974) studied the resistance of 92 sorghum cultivars to rice weevils, measuring the degree of resistance by the number of progeny emerged from 100 kernels of each cultivar in a free-choice test. He found that Shallu MP10 which had the second hardest kernels, yielded the smallest average number of weevil progeny. Fadelmula (1983) also found a high correlation between hardness of sorghum varieties and the number of rice weevil progeny. Russell and Rink (1965) indicated that the correlation coefficient for relative hardness of four sorghum varieties and numbers of first-generation adults was significant; but not for hardness and developmental period of the same generation.

Morrison (1964) tested the effect of the particle size of sorghum grain on development of maize weevils. The results showed that maize weevils could maintain a low level of infestation in coarsely and finely-ground particles of sorghum, but they did better in halved kernels and best in whole kernels. Maneechoti (1974) found a negative relationship between size of sorghum kernels and resistance to rice weevils.

In this study, rice weevils, *Sitophilus oryzae* (L.) reared in sorghum or millet were used to evaluate the effect of the parent rearing medium on the resistance/susceptibility of contrasting cultivars of sorghum and millet to rice weevils.

Materials and Methods

Before starting the test, rice weevils (RW), *Sitophilus oryzae* (L.) were cultured in sorghum or millet for at least ten generations to obtain test insects adapted to the types of test grain, although not the same cultivars. The four cultivars used in this test were the same as used in the previous experiments.

Using a binocular microscope, 100 uniform, undamaged kernels that had been equilibrated in the rearing room were selected from each sorghum and millet cultivar. Six female and 3 male, 1-2-week-old rice weevils from sorghum cultures were placed with each 100 kernels of each sorghum and millet cultivar in a 43 X 43 X 17 mm plastic box with a screen-covered 12.7-mm hole in the lid. The parent weevils were removed after 7 days. The boxes were then kept in the rearing room and after three weeks were observed daily for 5 weeks for adult emergence. The number of adults emerged and dates of emergence in each cultivar were recorded. The same test was done using the millet and sorghum cultivars and rice weevil parents reared in millet. The tests were repeated four times.

For each parent rearing medium the number of emerged insects and dates of emergence for each cultivar were analyzed statistically (ANOVA).

Results and Discussion

Effect of Parent Rearing Medium on the Number of Rice Weevil Progeny

The analysis of variance indicated no significant differences in numbers of rice weevil progeny for any cultivar for parents reared in sorghum or millet. Also there was no interaction between parents origin and cultivar reaction. However, there were significant differences in the numbers of progeny among different cultivars.

The mean numbers of rice weevil progeny were significantly greatest in millet 2090 X 7024 (43.5 and 41.8) from parents reared in sorghum and millet, respectively, (Table 1). The mean numbers of progeny from Dekalb 32 (22.0 and 22.5) and Shallu MP10 (18.0 and 15.3) were not significantly different for parents from sorghum and millet, respectively, although less progeny were yielded by Shallu. This could be due to the similar relative hardness of the sorghum cultivars. Millet 4039 yielded the fewest weevil progeny for parents from both rearing media (8.0 and 7.3).

Effect of Parent Rearing Medium on the Developmental Period of Rice Weevil Progeny

The analysis of variance indicated no significant differences in the mean developmental periods of rice weevil progeny in the same cultivar, when parents were reared in different media (sorghum or millet). There was no interaction between parent rearing medium and developmental periods in the cultivars. There were significant differences in developmental periods among the different cultivars.

Shallu MP10 yielded the longest developmental periods (38.7 days and 39.3 days) for insects with parents from sorghum and millet, respectively, which were significantly different from those in other cultivars (Table 2). Rice weevils that developed in Dekalb sorghum and millet 4039 from parents reared in sorghum and millet were not significantly different in developmental periods (36.6 days and 37.3 days) and (36.8 days and 37.5 days), respectively. Rice weevils emerged from millet 2090 X 7024 had the shortest developmental periods (34.3 days and 35.2 days). The developmental period relationships of rice weevils emerged from different cultivars are similar to those found in part one.

In all cultivars rice weevils from parents reared in sorghum had shorter developmental periods than those from parents reared in millet (Fig. 1), although the differences were not significant within cultivars. The numbers of rice weevil progeny yielded by the cultivars were larger for parents reared in sorghum except for Dekalb; again the differences were not significant within cultivars.

The mean numbers of rice weevil progeny yielded by Dekalb and Shallu were not significantly different, although fewer weevils with significantly longer developmental periods developed in Shallu. Kernels of Shallu and Dekalb are similar in size, thus this had no effect on the results. Again Shallu has more vitreous endosperm than Dekalb, which may have influenced results.

Significantly more weevil progeny were produced in millet 2090 X 7024 and their developmental periods were shorter than for those from millet 4039 (Fig. 1). Seifelnasr (1984), in a free-choice test, found that millet 4039 was more resistant to rice weevils than 2090 X 7024, as measured by progeny production. This might be due to the differences in size or hardness of kernels; millet 2090 X 7024 has larger and softer kernels. However, texture or toughness of pericarp, chemical components, or other factors not tested, could have affected the results for both grains. Wongo (1986) tested the effect of smoothness of different sorghum cultivars on the production of rice weevils. He found that more progeny of rice weevils were produced in the cultivar with the rough surface texture, and the smooth-surfaced cultivar yielded the lowest number. Maneechoti (1974) and Kossou (1981), however, found that smoothness of the kernels does not appear to be a factor in resistance to rice weevils for sorghum and millet, respectively.

Sorghum or millet as rearing medium for test insects had no effect on resistance/susceptibility of 2 sorghum and 2 millet cultivars as determined by number of weevil progeny and their developmental periods. These results did not conform to the Hopkins' host selection principle (Hopkins, 1916).

Table 1. Mean numbers of *Sitophilus oryzae* progeny emerged from sorghum or millet cultivars infested with parents reared on sorghum or millet. (4 replicates of 100 kernels each, 6 females and 3 males, 7 days oviposition).

Cultivar	Parent rearing medium			Grouping
	Sorghum		Millet	
Dekalb 32	22.0	n.s.	22.5	b
Shallu MP10	18.0	n.s.	15.3	b
Millet 2090 X 7024	43.5	n.s.	41.8	a
Millet 4039	8.0	n.s.	7.3	c

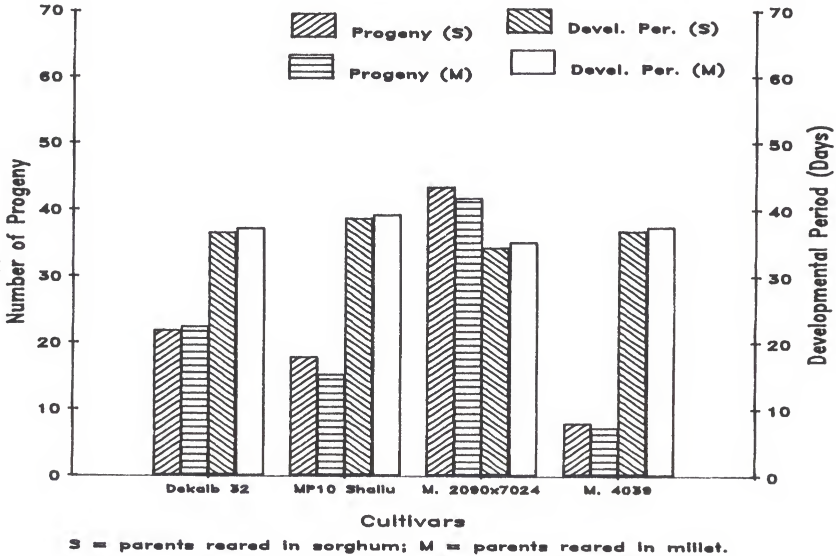
Means followed by the same letter are not significantly different (Alpha = 0.05), as determined by Tukey's Studentized Range Test.

Table 2. Mean developmental period (days ± 4) of *Sitophilus oryzae* progeny emerged from sorghum or millet infested with parents reared in sorghum or millet. (4 replicates of 100 kernels each, 6 females and 3 males, 7 days oviposition).

Cultivar	Parent rearing medium			Grouping
	Sorghum		Millet	
Dekalb 32	36.6	n.s.	37.3	b
Shallu MP10	38.7	n.s.	39.3	a
Millet 2090 X 7024	34.3	n.s.	35.2	c
Millet 4039	36.8	n.s.	37.5	b

Means followed by the same letter are not significantly different (Alpha = 0.05), as determined by Tukey's Studentized Range Test.

Figure 1. Mean developmental periods and numbers of *Sitophilus oryzae* (L.) progeny emerged from sorghum and millet cultivars infested by parents reared in sorghum or millet.


Progeny (S)
Progeny (M)
Devel. Per. (S)
Devel. Per. (M)
Number of Progeny
Developmental Period (Days)
0
10
20
30
40
50
60
70
Dekalb 32
MP10 Shallu
M. 2090x7024
M. 4039
Cultivars
S = parents reared in sorghum; M = parents reared in millet.

PART III

SUCCESS OF FEEDING OF FIRST, SECOND OR THIRD INSTARS OF *CORCYRA CEPHALONICA* (STAINT.) AND *CADRA CAUTELLA* (WALKER) ON SOUND OR DAMAGED KERNELS OF SORGHUM OR MILLET CULTIVARS.

Introduction

The rice moth, *Corcyra cephalonica* (Staint.) and the almond moth, *Cadra cautella* (Walker) are important pests on stored grains. They feed mainly on the germ. The success of the first instar larvae of several moth species to feed and develop on whole or damaged grains has been studied (Chaudhary and Bhattacharya, 1976; Dobie, 1978; Madrid and Sinha, 1982).

There is a lack of information on the success of feeding of larger instars on damaged vs. undamaged grain kernels. Barrer (1981) reported on the biology of lepidopterans associated with stored grain. He stated that, for both *C. cephalonica* and *C. cautella* broken seeds are more suitable as foods than either whole seeds or flours. He also indicated that in case of population pressures, and especially under inadequate food situations, large larvae tend to wander in search of better conditions, but he did not indicate whether those larger larvae were successful in attacking *sound* kernels.

This study was to test the success of the first, second, or third instar larvae of the rice moth and almond moth to feed and develop to the next instar on sound or damaged kernels of sorghum and millet.

Materials and Methods

The rice moth (RM), *Corcyra cephalonica* (Staint.) and the almond moth (AM), *Cadra cautella* (Walker) were obtained from stock cultures that had been maintained for many generations on a special moth medium. They were then cultured in sorghum or millet, including some coarsely-ground grain, for at least three generations to obtain test insects accustomed to these grains. The sorghum test cultivars used were Dekalb 32 (floury) and Shallu MP10 (vitreous), and the test millets were 2090 X 7024 (large and soft) and millet 4039 (small and hard). Cultures and tests were maintained in the conditioned rearing room ($27\pm1^{o}C$, $67\pm3\%$ RH and 14L:10D photoperiod).

Using a binocular microscope, 20 uniform, undamaged, and equilibrated (in the rearing room) kernels were selected from each sorghum cultivar. An insect pin was used to puncture, at the border of the germ, the pericarp of 10 kernels, selected randomly from each cultivar. The kernels were then kept separately in equilibrated #0 gelatin capsules.

Twenty to 40 newly-emerged, unsexed RM adults reared in sorghum were collected, placed in an oviposition jar. Four days later eggs were sieved out and placed in flat bottom vials (60-80/vial) which were closed with cork stoppers, labelled, and held for hatching in the rearing room. When a sufficient number of 0- to 24-hour-old larvae were obtained in one day, a fine camel hair brush was used to place each larva with one of the kernels in a gelatin capsule. Ten days later the capsules were checked and the success or failure of each first instar larva to feed and develop to the second instar which was indicated by an increase in the size of the larval head capsule, and the presence of the shed first instar head capsule; also the presence of germ damage to the kernel.

For determining the success of feeding of the second or third instars, each of sixty 0- to 24-hour-old RM larvae were placed individually in a small amount of finely-ground sorghum in a #0 gelatin capsule for 6 days (to develop to the second instar) or 10 days (to develop to the third instar). Then the second or third instar larvae were placed singly with single damaged or undamaged sorghum kernels, as was done for first instar larvae. They were observed to determine whether or not they fed and developed to the next instar.

The same test was done using the millet cultivars and larvae produced in finely-ground millet. Similarly, larvae of AM whose parents were reared in sorghum or millet were tested for ability to feed on kernels of the sorghum or millet cultivars, respectively. However, in the case of AM the eggs were collected after 3 days oviposition instead of 4 days. Each test was repeated four times.

The success of feeding of first, second, or third instars of RM or AM on damaged vs. undamaged sorghum or millet kernels was analyzed statistically (ANOVA).

Results and Discussion

Rice Moth

The sound kernels of sorghum cultivars Dekalb 32 and Shallu MP10 were completely resistant to the first, second, and third instars of rice moth, *Corcyra cephalonica* (Table 1). The sound millet kernels were resistant to the first instar, but not completely to the second or third instars. The number of second and third instars that fed and developed to the next instar on sound kernels of millet 2090 X 7024 (4.25 and 5.50) and millet 4039 (4.50 and 5.75) were not significantly different for each instar, but success was significantly different from that in the sorghum cultivars.

Damaged kernels of all cultivars were equally susceptible to the first, second, or third instars of the rice moth (Table 1).

On sound millet kernels about half of the second and the third instars of rice moth were able to feed and develop to the next instar, but not on the sound sorghum kernels.

Perhaps the smaller size of millet kernels made them more easily chewed. Texture or structure of the pericarp may have influenced the differences (De Francisco, 1982).

Almond Moth

The almond moth, *Cadra cautella* failed completely to feed on sound sorghum as first, second, or third instars, but a few fed on sound millet kernels and attained the next instar, especially the third instars (Table 2). As sound kernels, millet 2090 X 7024 was the most susceptible cultivar to the almond moth; an average of 0.25, 1.25, and 2.75 AM larvae developed from first to second, second to third, and third to fourth instars, respectively, but it was significantly more susceptible only to the third instar. On millet 4039 0.5 and 2.0 AM larvae developed from second and third instars to the third and fourth instars, respectively. It was significantly more susceptible to the third instar than to the first or second.

The almond moth was more successful in feeding and development on damaged sorghum than on damaged millet. The success of feeding and development of the first instar to the second on damaged sorghum kernels was perfect (10.00) for both cultivars and significantly different from that on damaged millets (6.75 and 6.25 for millet 2090 X 7024 and millet 4039, respectively). For the second instar the success of feeding and development to the third instar was also perfect on damaged sorghums (10.00) for both cultivars and slightly, but not significantly, different from that in damaged millets (9.50 and 9.25). The third instars fed and completed development to the fourth instar on all damaged Dekalb kernels (10.00), followed by those on damaged Shallu (9.75) and millet 4039 (9.75), and then on millet 2090 X 7024 (9.25). These numbers were not significantly different from each other.

These results indicated that the almond moth larvae, especially as first instars, would more likely be successful on sorghum than millet in presence of damage. The opposite is true for sound kernels. The smaller size of millet kernels or pericarp characteristics may have been responsible. Within millet cultivars, sound kernels of 2090 X 7024 were more susceptible than 4039 to the almond moth. Kernels of the former are larger. Kernels of 2090 X 7024 are softer and have a rougher pericarp. Wongo (1986), in a no-choice test, found that more Angoumois grain moth progeny emerged from rough than smooth-surfaced sorghum kernels. Perhaps the rougher pericarp was easier for the first, second, and third instars to chew through to the inside of the kernels.

Sound millet or sorghum kernels were virtually immune to attack by first instar larvae of both insects. Sound sorghum kernels were almost immune to all three instars of both insects. Damaged kernels of both sorghum and millet cultivars were very susceptible to all three instars of both insects. The second and third instars of the rice moth successfully attacked about half of the sound millet kernels.

The sound kernels in the study were very carefully selected, thus would resist infestation by these moths much better than grain normally found in storage, which usually has enough damaged kernels to support active moth populations.

Table 1. Mean numbers of *Corcyra cephalonica* larvae that developed to the next instar when placed singly with single sound or damaged sorghum or millet kernels. (4 replicates of 10 kernels each).

Variety	Larvae placed with: Sound kernels	Larvae placed with: Damaged kernels
	First to second instar	
Dekalb 32	0.00 a	9.50 a
Shallu MP10	0.00 a	9.50 a
Millet 2090 X 7024	0.00 a	9.25 a
Millet 4039	0.00 a	9.50 a
	Second to third instar	
Dekalb 32	0.00 b	9.25 a
Shallu MP10	0.00 b	10.00 a
Millet 2090 X 7024	4.25 a	9.75 a
Millet 4039	4.50 a	10.00 a
	Third to fourth instar	
Dekalb 32	0.25 b	9.75 a
Shallu MP10	0.00 b	10.00 a
Millet 2090 X 7024	5.50 a	9.75 a
Millet 4039	5.75 a	10.00 a

Means in the same column for the same instar followed by the same letter are not significantly different (Alpha = 0.05), as determined by Tukey's Studentized Range Test.

Table 2. Mean numbers of *Cadra cautella* larvae that developed to the next instar when placed singly with single sound or damaged sorghum or millet kernels. (4 replicates of 10 kernels each).

Variety	Larvae placed with:	
	Sound kernels	Damaged kernels
	First to second instar	
Dekalb 32	0.00 a	10.00 a
Shallu MP10	0.00 a	10.00 a
Millet 2090 X 7024	0.25 a	6.75 b
Millet 4039	0.00 a	6.25 b
	Second to third instar	
Dekalb 32	0.00 a	10.00 a
Shallu MP10	0.00 a	10.00 a
Millet 2090 X 7024	1.25 a	9.50 a
Millet 4039	0.50 a	9.25 a
	Third to fourth instar	
Dekalb 32	0.00 b	10.00 a
Shallu MP10	0.00 b	9.75 a
Millet 2090 X 7024	2.75 a	9.25 a
Millet 4039	2.00 ab	9.75 a

Means in the same column for the same instar followed by the same letter are not significantly different (Alpha = 0.05), as determined by Tukey's Studentized Range Test.

PART IV

GRAIN WEIGHT LOSSES AND NUMBERS OF KERNELS DAMAGED BY INDIVIDUAL CORCYRA CEPHALONICA (STAINT.) OR CADRA CAUTELLA (WALKER) LARVAE DURING DEVELOPMENT IN SORGHUM OR MILLET

Introduction

The rice moth, *Corcyra cephalonica* (Staint.) and the almond moth, *Cadra cautella* (Walker) have been reported as pests of many types of stored products (Mookherjee, et al., 1969; Sharma et al., 1977).

Mookherjee and Khanna (1971) reported that a single larva of the almond moth is capable of feeding on and destroying an average of 12.28 wheat germs. Osman (1984) found that the dry weight losses done during development of 100 rice moth larvae on 100 grams of millet or sorghum were 16.02 and 20.73%, respectively, at 12.1% MC. The developmental periods of rice moths in millet and sorghum of the same moisture content were 55.35 days and 54.01 days, respectively.

The objectives of these tests were to compare the developmental periods, weights of pupae, and numbers of larval instars of rice moths and almond moths that developed in the two cultivars of sorghum and two cultivars of millet; and calculate the amount of damage (by weight loss and number of kernels damaged) resulting from feeding of the larvae during their development.

Materials and Methods

Twenty to 40 newly-emerged rice moth (RM) adults were collected from millet cultures and placed in an oviposition jar. Four days later eggs were collected, placed in flat-bottom vials (60-80 eggs each), then incubated in the rearing room until 40 or more 0- to 24-hour-old larvae could be obtained at the same time. One hundred whole and equilibrated (in the rearing room) kernels of each millet cultivar were selected, the pericarp of each was punctured at the border of the germ with an insect pin to provide feeding sites for the larvae. Five kernels of each cultivar were weighed together and placed in each equilibrated and marked #0 gelatin capsule (20 such capsules were prepared for each cultivar). Using a fine, camel hair brush, one newly-hatched larva was transferred to each capsule. Only 5 kernels/capsule were used so that success of feeding of the first instar could be more easily detected. The capsules were then kept in the rearing room for 2 weeks. Meanwhile, 1,140 additional whole, equilibrated kernels of each cultivar were selected and each damaged at the germ borders. Ninety-five kernels of each cultivar were weighed and placed in each of 12 plastic boxes (18 X 18 X 17 mm). When the larvae were two weeks old 12 were selected randomly and along with the 5 kernels each had been with, each was transferred to one of the 12 boxes containing 95 damaged kernels. The additional 95 kernels were expected to provide sufficient food for complete development for each larva. A small piece of corrugated cardboard paper (15 X 10 mm) was placed on top of the kernels in each box to provide a pupation site for the larva. Two weeks later boxes were checked for pupae, which were removed and weighed and the remaining boxes were checked every three days for pupae. Larval head capsules were searched for among the kernels in the boxes from which pupae had been removed; they were counted, measured, and the kernels were cleaned of frass and kept in the rearing room for at least 2 weeks to be moisture-equilibrated without the presence of insects. It was expected that the moisture content equilibrated to about the same as that of the kernels when initially weighed. The kernels in each box were weighed. The pupae were kept in small labelled vials until the adults emerged and were sexed. Pupae which did not produce adults were considered to be male or female depending upon their weights, and data were used accordingly.

The same test was done using almond moths (AM) in millet, but a 3-day oviposition period was used. The AM and RM were also similarly tested in sorghum cultivars, but due to kernel size differences only 60 kernels of each sorghum cultivar were placed in each box, including the 5 with which the newly-hatched larva was placed. All tests were repeated 4 times.

Developmental periods, numbers of instars, weights of pupae, kernel weight losses, and numbers of kernels damaged were statistically analyzed for each cultivar (ANOVA).

Results and Discussion

Results revealed that more first instar larvae of RM (90 to 100%) were alive 14 days after placing them with the five kernels of millet in the gelatin capsules, while 65 to 100% of the AM larvae were alive. In sorghum both insects had about the same success, 90 to 100% for RM and 85 to 100% for AM. After transferral to the boxes (two weeks to pupation) AM larvae performed better than RM larvae in each grain. All but two AM larvae pupated; these two died. Those which pupated had more uniform developmental periods in sorghum (26-32 days) than in millet (25-46 days in three replicates together and 31-96 days in one replicate). Large numbers of RM larvae stopped feeding and apparently diapaused in both sorghum and millet. Tests for RM were stopped when these larvae were 62-64 days old in sorghum and 106-113 days old in millet. Results for RM were analysed separately for larvae and pupae.

Rice Moth

The mean developmental periods, numbers of instars, pupal weights, numbers of kernels damaged and grain weight losses for larvae which completed development were observed and were dealt with separately for millet and sorghum. (Tables 1, 2, 4, 5). Because RM larvae pupated in millet were all females in two of the four replicates General Linear Models (GLM) were used for statistical analysis instead of ANOVA (Tables 4 and 5). Larvae which did not develop to pupae were weighed and evaluated for the same factors as larvae that pupated. These larvae were full-grown and had stopped feeding.

The larvae that developed and pupated in Dekalb 32 and Shallu MP10 were similar in mean developmental periods (44.1 days and 42.7 days), numbers of instars (6.8 and 6.9), numbers of kernels damaged (33.4 and 32.3 of 60), grain weight losses (98.52 and 105.18 mg), and percent weight losses (7.2 and 7.5, respectively). However, the mean pupal weights were significantly greater for insects that developed in Shallu, where the kernels have more vitreous endosperm (Table 1).

When females and males were compared in Dekalb and Shallu, the relationships were found to be similar for both cultivars (Table 2); i.e., the mean larval developmental periods and numbers of instars for females and males in each cultivar were not significantly different. The means for pupal weight, number of kernels damaged, grain weight losses and percent grain weight losses were greater for females than males in both Dekalb and Shallu.

Rice moth larvae with exceptionally long developmental periods (did not pupate) had more instars than those with shorter larval periods; they averaged 7.8 and 7.6 in Dekalb and Shallu, respectively, and ranged from 6 to 9. When RM larvae that had not pupated by 62-64 day were weighed, those that had developed in Shallu were significantly heavier than those that had developed in Dekalb (26.22 and 21.68 mg, respectively). The mean numbers of kernels damaged and grain weight losses during development of these larvae in the two sorghums were not significantly different (Table 3). The percent grain weight loss was higher for RM larvae developed in Dekalb.

Because millet tests were started earlier than the sorghum tests, they were not terminated until 106 to 113 days after infestation. Larvae that completed development in millet 2090 X 7024 and millet 4039 had average developmental periods of 54.7 and 56.1 days, numbers of instars of 6.7 in each cultivar, pupal weight of 16.32 and 14.83 mg, and damaged 60.9 and 68.1 kernels, and caused grain weight losses of 112.25 and 96.88 mg, respectively. None of these values for the two millets were significantly different (Table 4). RM larvae pupated in 4039 caused larger percent grain weight loss than those in 2090 X 7024. 4039 has smaller kernels than 2090 X 7024.

Males in both millet cultivars had significantly longer mean developmental periods (60.0 days for 2090 X 7024 and 67.3 days for 4039) than femals (49.3 and 44.9 days, respectively). The mean numbers of instars were similar for both sexes in each cultivar, while females had significantly greater pupal weights, 19.68 mg for 2090 X 7024 and 18.84 mg for 4039, compared to those of males, 12.97 and 10.82 mg, respectively (Table 5). Although mean numbers of kernels damaged and grain weight losses due to feeding of rice moth larvae were not significantly different for the two sexes in each cultivar, females caused more damage.

Larvae of the rice moth that had exceptionally longer larval periods in millet, 106 to 113 days, and still not pupated, had a similar number of instars in both cultivars of millet, ranged from 6 to 11 instars. These larvae were significantly heavier in millet 2090 X 7024 (17.26 mg) than those in 4039 (11.48 mg). Mean numbers of kernels damaged (of 100) by these rice moth larvae in each cultivar were similar (78.3 for 2090 X 7024 and 83.8 for 4039), the percent grain weight loss was greater for 4039 (17.4) than for 2090 X 7024 (13.4), while the mean grain weight losses were significantly greater for 2090 X 7024 with large and soft kernels (Table 6). The extent of damage resulted from feeding of rice moth larvae in different cultivars varied from one kernel to another (Plate 1).

Russell et al. (1980) made a laboratory study of two strains of rice moths on millet and sorghum at 28^{o}C and different relative humidities (70%, 30%, 20%, and 10%). They

Table 1. Mean larval developmental periods, numbers of larval instars, pupal weights, numbers of damaged kernels, and grain weight losses in sorghum cultivars during development of rice moths, *Corcyra cephalonica*. (4 replicates; 60 kernels per insect).

Variety	No. insects	Devel. period (days±2)	No.instars		Pupal weight (mg)	No. kernels damaged	Weight loss	
			mean	range			mg	%
Dekalb 32	23	44.1 a	6.8 a	6-8	16.70 b	33.4 a	98.52 a	7.2 a
Shallu MP10	13	42.7 a	6.9 a	6-9	21.35 a	32.3 a	105.18 a	7.5 a

Means in each column followed by dissimilar letters are significantly different (Alpha = 0.05), as determined by Tukey's Studentized Range Test.

Table 2. Mean larval developmental periods, numbers of larval instars, pupal weights, numbers of damaged kernels, and grain weight losses in sorghum cultivars during development of female and male rice moths, _Corcyra cephalonica_. (4 replicates; 60 kernels per insect).

Sex	No. insects	Devel. period (days±2)	No. instars		Pupal weight (mg)	No. kernels damaged	Weight loss	
			mean	range			mg	%
				Dekalb 32				
Female	16	43.9 a	7.2 a	6-8	20.47 a	37.9 a	116.55 a	7.9 a
Male	7	44.3 a	6.5 a	6-7	12.92 b	28.9 b	87.16 b	6.0 a
				Shallu MP10				
Female	7	41.1 a	7.0 a	-	25.95 a	38.5 a	121.77 a	8.9 a
Male	6	44.3 a	6.9 a	6-8	16.75 b	26.1 b	88.60 b	6.0 a

Means in the same column for the same cultivar followed by the same letter are not significantly different (Alpha = 0.05), as determined by Tukey's studentized Range Test.

Table 3. Mean numbers of instars, larval weights, numbers of damaged kernels, and weight losses of sorghum grain cultivars during feeding of rice moth larvae to diapause, _Corcyra cephalonica_. (4 replicates; 60 kernels with each larva).

Variety	No.[1/] insects	No. instars		Larval weight (mg)	No. kernels damaged	Weight loss	
		mean	range			mg	%
Dekalb 32	25	7.8 a	7-9	21.68 b	45.4 a	149.71 a	10.8 a
SHallu MP10	35	7.6 a	6-9	26.22 a	47.6 a	144.93 a	9.8 a

Means in the same column followed by the same letter are not significantly different (Alpha = 0.05), as determined by Tukey's Studentized Range Test.

[1/] All data are for larvae that had not pupated by 62 to 64 days after infestation.

Plate 1. Damage on sorghum and millet kernels due to feeding of rice moth, *Corcyra cephalonica* (60 X).

Aa. Slight and moderate damage on Dekalb 32 and Shallu MP10.

Ab. Moderately severe and severe damage on Dekalb 32 and Shallu MP10.

Ba. Slight and moderate damage on millet 2090 X 7024 and millet 4039.

Bb. Moderately severe and severe damage on millet 2090 X 7024 and millet 4039.

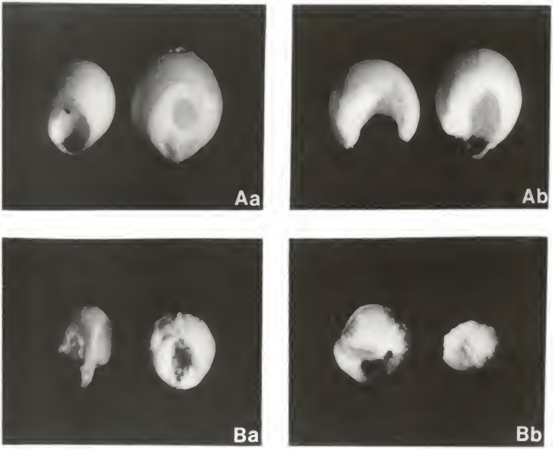

Aa
Ab
Ba
Bb

Table 4. Mean larval developmental periods, numbers of larval instars, pupal weights, numbers of damaged kernels, and grain weight losses in millet cultivars during development of rice moths, *Corcyra cephalonica*. (4 replicates; 100 kernels per insect).

Variety	No. insects	Devel. period (days±2)	No. instars		Pupal weight (mg)	No. kernels damaged	Weight loss	
			mean	range			mg	%1/
Millet 2090 X 7024	26	54.7 a	6.7 a	6-9	16.32 a	60.9 a	112.25 a	9.6
Millet 4039	37	56.1 a	6.7 a	5-9	14.83 a	68.1 a	96.88 a	13.4

Means in the same column followed by the same letter are not significantly different (Alpha = 0.05), as determined by Least Significant Difference Test (LSD).

1/ These were not statistically analyzed, because sample weights of the two millet cultivars were different.

Table 5. Mean larval developmental periods, numbers of larval instars, pupal weights, numbers of damaged kernels, and grain weight losses in millet cultivars during development of females and males of rice moths, *Corcyra cephalonica*. (4 replicates; 100 kernels per insect).

Sex	No. insects	Devel. period (days±2)	No.instars		Pupal weight (mg)	No. kernels damaged	Weight loss	
			mean	range			mg	%1/
			Millet 2090 X 7024					
Female	20	49.3 b	6.7 a	6-9	19.68 a	61.0 a	119.09 a	9.9
Male	6	60.0 a	6.8 a	6-8	12.97 b	60.8 a	105.42 a	9.4
			Millet 4039					
Female	22	44.9 b	6.7 a	5-9	18.84 a	71.1 a	99.51 a	14.0
Male	15	67.3 a	6.7 a	5-7	10.82 b	65.1 a	94.24 a	12.8

Means in the same column followed by the same letter are not significantly differnt (Alpha = 0.05), as determined by Least Significant Difference Test (LSD).

1/ These were not statistically analyzed, because sample weights of the two millet cultivars were different.

Table 6. Mean numbers of instars, larval weights, numbers of damaged kernels, and grain weight losses of millet cultivars during feeding of rice moth larvae to diapause, *Corcyra cephalonica*. (4 replicates; 100 kernels per insect).

Variety	No.[1] insects	No. instars		Larval weight (mg)	No. kernels damaged	Weight loss	
		mean	range			mg	%[2]
Millet 2090 X 7024	22	7.9 a	7-11	17.26 a	78.3 a	160.35 a	13.4
Millet 4039	10	8.3 a	6-9	11.48 b	83.8 a	113.27 b	17.4

Means in the same column followed by the same letter are not significantly different (Alpha = 0.05), as determined by Tukey's Studentized Range Test.

1/ All data are for larvae that had not pupated by 106 to 113 days after infestation.

2/ These were not statistically analyzed, because sample weights of the two millet cultivars were different.

found that as the relative humidities decreased the number of instars increased and correlated with the length of the developmental periods. Under the same conditions of temperature and relative humidities they found that some larvae had exceptionally long developmental periods, ranging from 97 to 155 days. The numbers of instars for those larvae ranged from 11 to 18. Thus it might have been expected that under conditions of the present tests, that some larvae would have long developmental periods. Russell et al. also indicated that the increase in instars did not result in heavier or larger adults. They also stated that the overall performance of both strains of rice moth was better on millet than on sorghum.

Almond Moth

The mean developmental periods of the almond moth larvae were similar in all four cultivars, however, they were slightly longer in the millets, 34.9 days in 4039 and 33.9 days in 2090 X 7024, compared to 26.9 days in Dekalb and 26.8 days in Shallu. Madrid and Sinha (1982) found that when almond moth larvae fed on kernels of wheat without bran (pericarp), they completed development to adults in 26 to 32 days, and 25 to 33 days on kernels with pericarp intact.

Almond moth larvae that developed in the sorghum and millet cultivars had similar average numbers of instars, 4.6

for those that developed in Dekalb and millet 2090 X 7024 and 4.5 for those that developed in Shallu and millet 4039. McGaughey (1978) reared almond moths in the laboratory at 25^{o}C and 60-70% RH on a diet consisting of cracked wheat, wheat shorts, wheat germ, brewer's yeast, glycerin, honey, water and mold inhibitors and found that it had 5 larval instars.

Pupae of almond moths developed in Dekalb and Shallu had similar average weights, 13.85 and 14.22 mg, repectively, which were significantly greater than weights of pupae in millet 2090 X 7024 (12.40 mg) and 4039 (11.61 mg) (Table 7).

The average numbers of sorghum and millet kernels damaged by almond moth larvae were significantly greater for millet 4039 (42.1), followed by those of millet 2090 X 7024 (36.6) and Dekalb (32.7) which were not significantly different. They damaged the fewest kernels of Shallu (24.5). However, the amount of damage done by larvae of the almond moth varied from one kernel to the other (Plate 2). In most cases the almond moth larvae fed on large proportions of the endosperm and parts of the pericarp in addition to complete consumption of the germ. This confirmed Madrid and Sinha's findings (1982), i.e., almond moth larvae enter through a break in the pericarp, eat the germ first, then while remaining inside the kernels, consume much of the endosperm and leave most of the pericarp uneaten.

The average grain weight loss due to feeding of single almond moth larvae (males and females together) was significantly greater in sorghums, 55.99 and 53.49 mg for Shallu and Dekalb, respectively, in contrast to 43.73 and 36.34 mg for millet 4039 and millet 2090 X 7024. The percent weight loss in millet 4039 (6.0) was greater than in millet 2090 X 7024 and in sorghums. The percent weight loss in 2090 X 7024 (3.7) was similar to those in sorghums (3.6 in Dekalb and 3.9 in Shallu), although for millet 100 kernels were used compared to 60 kernels for sorghums. these results are due to the differences in kernels size for the different cultivars.

Almond moth females caused greater grain losses in all four cultivars of sorghum and millet (65.13 mg in Shallu, 61.22 mg in Dekalb, 52.24 mg in millet 4039, and 44.00 mg in millet 2090 X 7024) when compared to males (46.85, 45.75, 35.21, and 29.47 mg, respectively) (Table 8). As expected, females damaged more germs (46.7 for 4039, 40.9 for 2090 X 7024, 35.7 for Dekalb, and 27.8 for Shallu) than males (37.4, 32.3, 29.7, 21.2, respectively), and females (pupae) had mean body weights greater than those of males.

The mean developmental periods and mean number of instars for the almond moth in different cultivars were not significantly different except for the numbers of instars of females that developed in Dekalb (4.9) were greater than those for males (4.4).

Plate 2. Damage on sorghum and millet kernels due to feeding of almond moth, _Cadra cautella_ (60 X).

Aa. Slight and moderate damage on dekalb 32 and Shallu MP10.

Ab. Moderately severe and severe damage on Dekalb 32 and Shallu Mp10.

Ba. Slight and moderate damage on millet 2090 X 7024 and millet 4039.

Bb. Moderately severe and severe damage on millet 2090 X 7024 and millet 4039.

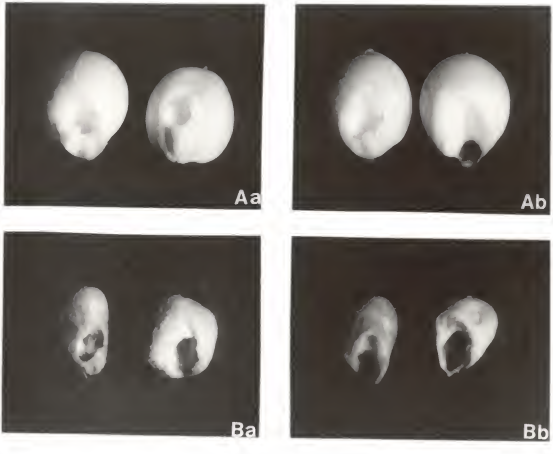

Aa
Ab
Ba
Bb

Table 7. Mean larval developmental periods, numbers of larval instars, pupal weights, numbers of damaged kernels, and grain weight losses in sorghum or millet cultivars during development of almond moth, *Cadra cautella* (males and females together). (4 replicates; 12 insects each; 60 kernels of sorghum or 100 kernels of millet for each insect).

Variety	No. insects	Devel. period (days±2)	No. instars		Pupal weight (mg)	No. kernels damaged	Weight loss	
			mean	range			mg	%1/
Dekalb 32	48	26.9 a	4.6 a	4-6	13.85 a	32.7 a	53.49 a	3.6
Shallu MP10	48	26.8 a	4.5 a	4-6	14.22 a	24.5 c	55.99 a	3.9
Millet 2090 X 7024	46	33.9 a	4.6 a	4-6	12.40 ab	36.6 b	36.34 b	3.7
Millet 4039	48	34.9 a	4.5 a	4-7	11.61 b	42.1 a	43.73 b	6.0

Means in the same column followed by the same letter are not significantly different (Alpha = 0.05), as determined by Tukey's Studentized Range Test.

1/ These were not statistically analyzed, because sample weights and numbers of millet and sorghum kernels were different.

Table 8. Mean larval developmental periods, numbers of larval instars, pupal weights, numbers of damaged kernels, and grain weight losses in sorghum or millet cultivars during development of almond moth, *Cadra cautella*. (4 replicates; 12 insects each; 60 kernels of sorghum or 100 kernels of millet).

Sex	No. insects	Devel. period (days±2)	No. instars		Pupal weight (mg)	No. kernels damaged	Weight loss	
			mean	range			mg	%1/
Dekalb 32								
Female	22	27.5 a	4.9 a	4-6	15.76 a	35.7 a	61.22 a	4.2
Male	26	26.2 a	4.4 b	4-5	11.94 b	29.7 a	45.75 b	3.1
Shallu MP10								
Female	28	27.3 a	4.6 a	4-6	16.37 a	27.8 a	65.13 a	4.3
Male	20	26.3 a	4.4 a	4-5	12.07 b	21.2 b	46.85 b	3.1

Table 8. (concluded)

Sex	No. insects	Devel. period (days±2)	No. instars		Pupal weight (mg)	No. kernels damaged	Weight loss	
			mean	range			mg	%[1]
			Millet 2090 X 7024					
Female	33	32.1 a	4.6 a	4-6	14.52 a	40.9 a	44.00 a	4.0
Male	13	35.8 a	4.6 a	4-5	10.28 b	32.3 b	29.47 a	2.6
			Millet 4039					
Female	27	34.7 a	4.6 a	4-6	13.40 a	46.7 a	52.24 a	6.9
Male	21	35.2 a	4.5 a	4-7	9.83 a	37.4 b	35.21 b	4.7

Means in the same column for the same cultivar followed by dissimilar letters are significantly different (Alpha = 0.05), as determined by Tukey's Studentized Range Test.

[1] These were not statistically analyzed, because sample weights and numbers of millet and sorghum kernels were different.

SUMMARY AND CONCLUSIONS

This study was to evaluate the effect of vitreousness of kernels of two sorghum cultivars and hardness and kernel size of two millet cultivars on the development of the rice weevil, the lesser grain borer, the rice moth, and the almond moth. All tests were conducted in a conditioned rearing room (27±1°C, 67±3% RH, and 14L:10D photoperiod) in the Stored-Product Insects Laboratory, Department of Entomology, Kansas State University.

Ten sound kernels or 20 damaged kernels, from each cultivar, each with one rice weevil eggplug or one 0- to 24 hour-old lesser grain borer larva, respectively, were placed individually in #0 gelatin capsules until adult emergence (4 replicates). Both species caused more kernel weight loss in sorghum than in millet. Among sorghum cultivars, both insects caused equal amounts of weight loss on the floury or vitreous kernels. Among millets, the soft large kernels lost more weight than the small, hard ones for both rice weevils and lesser grain borers. Rice weevils that emerged from sorghum were heavier than those that emerged from millet, while lesser grain borers had variable weights. Developmental periods of the lesser grain borer were similar in all four cultivars, while they were variable for the rice weevil.

Rice weevil adults reared in sorghum or millet cultures were used to infest 200 sound kernels of sorghum or millet from each cultivar (4 replicates). Twelve females and 6 males from each medium were placed with the 200 kernels in a 43 X 43 X 17 mm plastic box for 7 days oviposition. Adults were then removed and kernels were kept until progeny emergence. There was no effect of the parents' rearing media on numbers of weevil progeny or on their developmental periods, i.e., mean numbers of weevils produced in the same cultivar but from parents reared in sorghum or millet were similar, and their developmental periods were similar.

The first, second, or third instars of the rice moth or the almond moth were placed individually with individual sound or damaged kernels of each of the four cultivars. The three instars of both insects failed to feed on the carefully selected sound sorghum kernels, while the second and third instars of the rice moth fed and developed to the next instars on about half of the sound kernels of both millet cultivars; the third instars of the almond moth fed and developed to the fourth instars on about one-fourth of the sound kernels of millet cultivars. The first, second, or third instar larvae of the rice moth and the second and third instar larvae of the almond moth were equally successful in feeding and developing to the next instars on damaged kernels of sorghum and millet.

Individual larvae of rice moths and almond moths were also placed with bulks of kernels (60 whole kernels from each sorghum cultivar or 100 whole kernels from each millet cultivar) in 18 X 18 X 17 mm plastic boxes and left there to pupate. Large numbers of rice moth larvae stopped feeding as full grown larvae and diapaused in both sorghum and millet. Those which pupated had similar pupal weights in both millet cultivars as well as the more floury sorghum kernels, but were heavier in the vitreous sorghum kernels. The weight losses were similar in all cultivars, while more kernels were damaged in millet (smaller kernels) than in sorghum. The number of larval instars were similar in all cultivars, although the larval developmental periods for insects which pupated were longer in millet cultivars. This is because tests in the millet cultivars were conducted for longer periods and some of the diapausing larvae pupated just before stopping the tests. Males produced in all cultivars were lighter in pupal weight than females. In sorghum cultivars males consumed less food and damaged fewer kernels than females, while in millet both sexes caused similar amounts of damage. In both grains the almond moth larvae, unlike rice moth larvae, had uniform developmental periods and all but one pupated after a "normal" larval period. They had similar mean numbers of instars in the four cultivars. Pupae produced in sorghum were heavier and as larvae caused more grain weight loss than those produced in millet. Males of the almond moth produced in all four cultivars were lighter than females, damaged fewer kernels, and caused smaller grain weight losses.

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SUCCESS OF DEVELOPMENT AND EXTENT OF FEEDING DAMAGE OF STORED-PRODUCT INSECTS IN CULTIVARS OF SORGHUM AND MILLET

by

NOUR AWAD ELKARIM SINADA

B.Sc. (1982) Khartoum University
Sudan

AN ABSTRACT OF A MASTER'S THESIS

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Two cultivars of sorghum and two cultivars of millet were used to evaluate the damage and weight losses caused during development of rice weevils, *Sitophilus oryzae*; lesser grain borers, *Rhyzopertha dominica*; rice moths, *Corcyra cephalonica*; or almond moths, *Cadra cautella*; on single kernels or bulks of kernels.

Individual rice weevils and lesser grain borers caused more weight losses in sorghum than in millet. Rice weevils that emerged from sorghum cultivars were heavier than those emerged from millets; their developmental periods were variable. Lesser grain borers had similar developmental periods in all four cultivars, but the weights of the emerged adults were variable.

Sound kernels of sorghum cultivars were resistant to the first, second or third instars of rice moths and almond moths. About 50% of the second and third instars of rice moths successfully fed and developed to the next instars on sound kernels of millet. Kernels of all four cultivars that were damaged (punctured using a pin) were equally susceptible to all three instars of the rice moth. The first instars of the almond moths were less successful in attacking damaged kernels of millet than those of the rice moth, but the second and third instars of both insects had equal success in attacking damaged kernels of each grain.

In a bulk of 60 or 100 damaged kernels of each sorghum or millet cultivar, respectively, rice moth larvae caused similar grain weight losses as they developed from hatching to pupation. The insects damaged more kernels of millet than sorghum and their mean developmental periods were longer in millet. Pupae produced in the sorghum cultivar that had more vitreous endosperm were heavier than those produced in the other three cultivars. The almond moth larvae caused greater weight losses in sorghum cultivars than in millets. The mean numbers of kernels damaged were variable. Pupae of almond moths produced in sorghums were heavier than those in millets; their developmental periods were similar in all cultivars.